SELECTION OF A WEAKER DESIRED SIGNAL FOR TESTS

Motivation

The data in this chapter and later chapters of this report show that, as desired signal power at the input to a TV decreases, the amount of undesired power that the TV can tolerate on another channel also decreases. This means that a TV is most vulnerable to interference when operating at a low desired signal level—not a surprising result.

One might also hypothesize that, as the desired signal power D at the input to the TV decreases, the undesired signal power U necessary to cause picture degradation would decrease at the same rate. If this were true, the D/U ratio would remain constant, and interference rejection measurements would only need to be performed at a single power level to gain an understanding of the TV's rejection performance. From the test results in this report, it is clear that this hypothesis is false. In fact, the rate of change of threshold undesired signal with desired signal differs with channel offset between the desired and undesired channel and also varies with desired signal amplitude.

The variation of D/U ratio with signal amplitude—often in unexpected ways—suggests the need for rejection performance measurements at a variety of amplitudes. In Chapter 11, we subject a single TV to D/U measurements over a wide amplitude range to gain some insight into interference behavior. However, given that TV's are most susceptible to interference at low desired signal levels, we focus here on weak signals.

The range of desired signal levels that a DTV receiver can or should accommodate extends from:

- D_{MIN} (nominally -84 dBm) — the desired signal level at which a DTV receiver begins to experience visible picture degradation; -84 dBm is the threshold assumed by OET-69 for edge-of-coverage UHF reception and also the median channel-30 threshold of 28 consumer DTV receivers measured under the SHVERA Study; to,
- -8 dBm — the maximum DTV signal level anticipated by the ATSC Receiver Guidelines.

In between are the three levels at which ATSC A/74 defines interference rejection performance guidelines for DTV receivers:

- -68 dBm -- "weak"
- -53 dBm -- "moderate"
- -28 dBm -- "strong"

The measurements of rejection performance presented thus far in this chapter were performed at these three levels.

Note that the -68 dBm signal level designated by the ATSC as "weak" is 16 dB above the -84 dBm minimum signal level at which a typical DTV receiver can operate; that minimum signal level of -84 dBm is also the signal level assumed by OET-69 (FCC's document for predicting coverage of a TV station) to be available to a DTV receiver at the edge of coverage of a TV broadcast station.* Table 2-2 and Figure 2-3 of Chapter 2 showed that fully 84 percent of the coverage area of a broadcast station may experience desired signal levels weaker than -68 dBm, assuming that the same type of antenna system is used at all locations in the viewing area. This suggests a need to test at lower signal levels.

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* Section 73.622E of the rules (CFR 47) establishes 41 dBuV/m as the UHF DTV field strength at the noise-limited edge-of-coverage contour. This field strength is derived from a planning model in which a -84 dBm signal is delivered to the DTV input at the edge-of-coverage in order to enable at TV with a 7-dB noise figure and a 15-dB required signal-to-noise ratio to operate.

Signal Level Selection

Selecting a signal level for interference tests that represent a near edge-of-coverage condition is not straight-forward. Only about half of the 28 receivers tested for the SHVERA Study could produce an error-free picture with a channel-30 desired signal level matching the -84 dBm edge-of-coverage signal level assumed by OET-69, even without adding any interference, and a few TVs would produce no picture at all at this signal level. Among those receivers, the TV with the least UHF sensitivity required an input signal level about 2.6 dB larger than the -84 dBm level, while the most sensitive TV could operate at a signal level 1.3 dB weaker than -84 dBm. The spread between the most-sensitive and least-sensitive receivers was larger in the VHF band—as high as 15 dB.

If, in order to accommodate relatively insensitive receivers, a relatively high desired signal level is chosen as the measurement basis for rules to prevent interference to television, the resulting rules for a new service might permit interference levels that would limit the operation of the better receivers that can operate on weaker signals. Hence a decision was made to also test at a receiver-dependent desired signal level near the threshold of visible picture degradation (TOV) that occurs in the absence of interference, a level we have designated as D_{MIN}.

Table 2-2 and Figure 2-3 of Chapter 2 showed that a TV located beyond 84 percent of the maximum reception range (R_{MAX}) of the broadcast station (for a given antenna system) will receive signal levels at less than 3 dB of signal margin (*i.e.*, signal level relative to that needed for consistent, clear reception of the broadcast signal).* 29 percent of the coverage area falls in this region of less than 3 dB signal excess. Similarly, and 11 percent of the coverage area will exhibit a signal excess of less than 1 dB.†

The assumptions regarding coverage area are typically based on use of a high-gain outdoor antenna on a 10-meter mast. The percentages discussed above apply to such coverage area as long as the receiving system (including antenna gain and mast height) remains constant as one moves in to closer distances from the broadcast location. Thus, for example, 29 percent of the receiving coverage area would operate with less than 3-dB signal excess for customers with that receiving system. If, however, closer-in customers choose a lower-gain antenna, a lower mast height, or an indoor antenna location, those customers will operate with a shorter maximum possible range for consistent reception (R_{MAX}). Such customers would also operate with less than 3-dB excess signal whenever they are beyond 84% of the maximum reception range possible with *that* antenna system. In essence, the region with less than 3-dB excess signal repeats itself as 29 percent of the area of a smaller coverage circle corresponding to use of the lesser antenna system. Hence, the area where excess signal is less than 1 or 3 dB will be larger than the 11 and 29 percent values discussed here if closer-in customers choose lower-gain antennas or place those antennas at less optimal locations such as on a shorter outdoor mast or indoors. (We note that, while the simple model used in the above analysis is useful for estimating the relative importance of various values for signal excess, terrain and man-made structures in real-world locations will cause the numbers to vary from those shown here.)

Given that rejection performance tests are time consuming, a decision was made to make measurements at only one additional signal level beyond the three ATSC-specified levels. We chose to make this level dependent on the threshold reception performance of the individual receivers. Thus, we measured the desired signal level D_{MIN} at which TOV occurs for each receiver in the absence of interference. Interference rejection tests were then performed at a desired signal level 3 dB above this threshold. The

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* The repeated use of the number 84 is not a typographical error. This number appears in three contexts in this discussion: D_{MIN} is typically -84 dBm (a value also assumed in the rules); signal excess diminishes to 3 dB at 84 percent of the maximum reception range; and, 84 percent of the coverage area that can be achieved by a nominal receiver (*i.e.* with D_{MIN} of -84 dBm) will exhibit signal levels at the TV input that are below the ATSC-specified "weak" signal level.

† These percentages refer to fractions of the coverage area possible for a given TV receiver with a given antenna system and with flat local terrain.

desired signal level for these tests is designated as D_{MIN} + 3 dB. In addition, we extrapolated the measurements to a desired signal power of D_{MIN} + 1 dB in Chapter 12 by means of a modeling approach developed from a theoretical framework presented in Chapter 8.*

EFFECT OF DESIRED SIGNAL SOURCE

In preparing for the D_{MIN}-referenced measurements, D_{MIN} was measured for three receivers that been tested for the SHVERA Study, but the new measurements were found to be about 1 dB higher than the earlier SHVERA measurements.† While these differences could have been considered to be within measurement error, there was uncertainty about whether the difference could be attributed to differences between the SHVERA test setup and the current test setup or the use of different desired signal sources in the two test programs.

The signal source used in the SHVERA Study had failed irreparably while being used as an undesired signal source for channel-51 tests in the current program; however, a new signal source (Rohde and Schwarz SFU) had been procured late in the current test program. To evaluate the cause of 1-dB difference, the new SFU generator was substituted for the Sencore ATSC997 source that was used as the desired source for most of the testing described in this report. The result of the switch was a 1-dB improvement in measured sensitivity of the receivers—to results that matched the SHVERA test results.

Table 5-1 shows the observed differences in receiver threshold for various desired-signal configurations, *with the SFU-based measurements as the reference*. In all cases, the measurements were made at the output of the test configuration that was shown in Figure 4-1. The first measurement column shows the differences in measured D_{MIN} using the ATSC997 in the test setup as shown in Figure 4-1 (including amplifiers A1 and A2, as well as three 6-dB pads) instead of the SFU. On average the ATSC997 in the "normal" test-setup configuration widely used in this report resulted in a receiver threshold about 0.9 dB higher than that when the SFU was used. The second column represents measurements to determine whether the difference was due to the ATSC997 itself, or the amplifiers that followed it. The third is a comparison to the SHVERA measurements.

In general, all three tested TVs appeared to require an input DTV signal level about 0.9 dB higher when the signal was supplied by the Sencore ATSC997 than when it was supplied by either the Rohde and Schwarz SFU or, based on the SHVERA test results, the Sencore RF Player (playing the "Hawaii_ReferenceA" file). This fact suggested that the signal quality of the ATSC997 was inferior to that of the other sources in a way that affected TV performance in a small, but measurable way. ***While a 0.9-dB discrepancy in TV receiver threshold may seem small, there was concern that it might be relevant when performing interference testing at levels only 3-dB above the receiver threshold.***

Measurements were performed on the desired signal at the output of the test setup in an attempt to determine the cause of the generator-dependence of receiver thresholds.

Figures 5-7 and 5-8 show the spectra of the desired signal at the output of the test setup using each of the two remaining 8-VSB sources. Figure 5-7 illustrates the higher noise floor of the ATSC997 relative to the SFU. If the ATSC997's noise floor extended through the desired signal band at a level roughly 40 dB below the desired signal, it would add to the TV receiver noise, which is generally expected to be about

* The decision to measure at D_{MIN} + 3 dB and extrapolate to D_{MIN} + 1 dB, rather than the other way around, was made because measurements become more sensitive to measurement error of the desired signal level and of D_{MIN} as the desired signal level approaches D_{MIN}.

† Martin, <SHVERA Study>, 2005, Chapter 4.

Table 5-1. Receiver Minimum Signal Level at TOV Versus Desired Signal Source

TV Receiver	D_{MIN} Measured Using Signal Source Shown Relative to D_{MIN} Measured Using Rohde & Schwarz SFU (dB)		
	Sencore ATSC997 (with amplifiers A1 & A2 as shown in Figure 4-1)	Sencore ATSC997 (bypassing external amplifiers)	SHVERA Result (Sencore RF Player in a Different Test Setup)
I1	0.77	0.87	-0.16
M1	1.06	1.24	0.05
N1	0.80	0.74	0.26
Mean	**0.87**	**0.95**	**0.05**

15 dB below the desired signal level at threshold. This would cause the total noise seen by the receiver to rise, relative to receiver-noise-only, by $10 \text{ Log}(1 + 10^{-(40-15)/10}) = 0.014$ dB. Clearly this is not the cause of the 0.9-dB change in receiver threshold.

The "flat top" of the ATSC997 signal exhibits a downward slope (visible in Figure 5-8) that projects to 0.7 dB across a 6-MHz channel width—far greater than the slope of the SFU spectrum, which projects to 0.04 dB across 6-MHz. We are unaware of a way to predict the impact of the spectral slope.

The pilot peak of the ATSC997 spectrum is 0.4 dB higher than that of the SFU—probably owing in part to the spectral slope.

Table 5-2 shows some additional measurements that were made on the desired signal at the output of the test setup for each desired signal source using an Agilent 89441A vector signal generator. Each measurement was an average of at least four successive readings that were obtained using the default settings of a control software package designed for DTV measurements.[*]

Table 5-2. Signal Quality Measurements on 8-VSB Sources

Desired Signal Source-->	ATSC997		SFU	
Vector Signal Analyzer Equalizer Setting-->	OFF	ON	OFF	ON
Modulation Error Ratio (MER) (dB)	29.88	32.50	39.10	40.86
Phase Error (deg)	2.43	1.51	1.01	0.92
Pilot Level (dB)	0.59	0.30	0.04	0.08

The modulation error ratios (MER) were examined to determine whether MER differences could account for the observed receiver performance differences. MER is definitely poorer for the ATSC997 source than for the SFU; however, even with the vector signal analyzer's equalizer turned off, the MER of the ATSC997 is still quite respectable. The ATSC states that the MER of a DTV transmitter should be greater than 27 dB in order to limit the impact on receiver threshold to about 0.25 dB.[†] The even higher 29.9 dB MER measured from the test setup using the ATSC997 source suggests that the impact on the receiver should be well under 0.25 dB.

[*] "Control Software for the HP89400 Vector Signal Analyzer for Measuring DTV and NTSC Signals", VSA5.BAS, Version 5.02, by Gary Sgrignoli. Note that it was necessary to exit the control software to turn the instrument's equalizer ON and OFF.

[†] Advanced Television Systems Committee, "Transmission Measurement and Compliance for Digital Television", ATSC Standard Doc. A/64 Rev A, 30 May 2000, p.5.

Eilers and Sgrignoli state that an MER of 27 dB will cause an increase in receiver threshold of 0.28 dB and explain that the increase can be computed "*by converting the 27-dB transmitter figure of merit value and the 15-dB receiver threshold value to equivalent linear relative powers, adding them together, and converting back to a logarithmic value resulting in 0.28 dB (= 0.3 dB) of increased noise.*"[*] Applying this technique to an MER of 29.88 dB, yields a 0.14-dB predicted increase in receiver threshold—nowhere near the observed 0.9-dB increase.

The cause of the roughly 1-dB degradation in receiver threshold when the ATSC997 supplies the desired signal remains unresolved. Similar results were obtained on repetition of the measurements—again swapping signal sources but changing nothing else in the test setup; this suggests that the difference was real rather than a result of measurement error.

Selection of a Desired Signal Source for Tests at D_{MIN} + 3 dB

Due to concern over possible impacts on interference rejection measurements to be made only 3-dB above the receiver threshold, a decision was made to make the "D_{MIN}+3 dB" measurements using the SFU as the desired signal source. The use of the SFU as the desired signal source for these measurements precluded testing on first-adjacent channel (N+1 and N-1) because neither the ATSC997 nor the bandlimited white noise source had adequate out-of-band spectral characteristics to support such testing. Hence, these measurements were performed (initially) only for an undesired signal (white Gaussian noise source bandlimited to match the 3-dB width of an 8-VSB signal) on channels N-2 through N-16 and N+2 through N+16.

Receipt of a Wavetech WS2100 RF Player shortly before the delivery deadline for this report enabled first-adjacent channel testing with a high-quality desired signal source at D_{MIN}+3 dB. The primary purpose of this player is playback of digitally-recorded RF captures of broadcast DTV signals received on TV antennas for evaluation of the multipath performance of DTV demodulators; however, the system is capable of performing as an unimpaired 8-VSB signal source if equipped with a recording of a high quality DTV signal. The Digital Television group of Advanced Micro Devices (AMD) created such a "recording" by mathematically deriving an 8-VSB signal from an MPEG2 transport stream. They provided this recording to us through Wavetech in the form of a file called "Muddy Waters". The WS2100, equipped with this file, was combined with an external upconverter to act as a desired signal source at a level of D_{MIN} + 3 dB for tests with the SFU as an undesired signal source on channels N-1 and N+1; those results are presented in the next section of this chapter.

In tests of the three receivers indicated in Table 5-1 using the Wavetech and the SFU, alternately, as desired signal sources, D_{MIN} values obtained with the two sources matched within 0.1 dB for each TV, with an average difference of 0.0 dB.[†] Thus, the TV receivers were unable to distinguish the signal quality of the Wavetech source from that of the SFU.

TESTS WITH DESIRED SIGNAL AT D_{MIN} + 3 DB

The results of the interference rejection measurements with the desired signal at D_{MIN} + 3 dB are shown in Figures 5-9 and 5-10. Though the ATSC provides no performance guidelines for interference rejection with D = D_{MIN} + 3 dB, the performance guideline for D = -68 dBm is included on the plots as a reference. Note that the vertical scale of the plots was extended 5 dB lower than the earlier D/U plots, because the

[*] Carl Eilers and Gary Sgrignoli, "Digital Television Transmission Parameters—Analysis and Discussion", IEEE Transactions on Broadcasting, Vol. 45, No. 4, Dec 1999, p.368.

[†] Both the Wavetech and SFU results were an average of 0.2 dB higher than the four-months-earlier SFU results from Table 5-1.

measurement limit of the test setup extends lower at D_{MIN} + 3 dB. *The measurement limitations at D = D_{MIN} + 3 dB are based on leakage from the undesired source into the desired channel.*

Qualitatively, the interference behavior at the lower desired signal level is similar to that at -68 dBm, with at least one notable exception; the N+7 interference susceptibility that appeared so significant at -68 dBm is quite low at D_{MIN} + 3 dB.

We also note that there was another of several discrepancies involving measurements of receiver G4. When D_{MIN} was measured for the N-1 and N+1 tests, the result was 5.5 dB higher than the two measurements performed three months earlier for the N+2 through N+16 and N-2 through N-16 tests. A repeat of the tests the next morning produced a match to the older results. Though receiver G8 was the best performing receiver among the eight in terms of interference rejection performance, measurements involving G8 were consistently inconsistent (a topic discussed further in Chapter 7).

SUMMARY OF FIFTH-GENERATION RECEIVER RESULTS

Figure 5-11 combines the measurements for each of the four desired signal levels—showing the *median* D/U ratio across the eight receivers at each channel offset and signal level. The three upper solid black lines correspond to the measurement limits applicable to the three upper curves on the plot—for D = -28 dBm, -53 dBm, and -68 dBm. Points falling on the respective black curves are at the measurement limit. The black line at the top of the shaded region is the measurement limit corresponding the measurements at D = D_{MIN} + 3 dB; it is based on leakage from the undesired source into the desired channel.

Figure 5-12 is similar to Figure 5-11, except the plot is in terms of undesired signal level (U) at the threshold. This portrayal differs in two significant ways from the D/U plots:
(1) Better performance is indicated by higher points on the plot rather than by lower ones;
(2) It makes clear that the greatest susceptibility to interference occurs at low desired signal levels—even though D/U ratio is often lowest (*i.e.*, best) at low desired signal levels.

We note that the measurement limitation shown in Figure 5-12 is the maximum undesired signal power that the test setup could inject into the receiver. The N-1 and N+1 offsets for D = -68 dBm and all of the offsets for D = D_{MIN} + 3 dB are subject to an additional limitation, shown only in the D/U plots, based on leakage of the undesired signal into the desired channel.

Based on the D/U plots one might conclude that interference at N+7 is a problem area; however, in terms of absolute levels of undesired signals that can cause interference there are 14 other channel spacings that are more vulnerable (N-7 through N+5, N+14, and N+15) to interference.

Figures 5-13 and 5-14 are repeats of the previous two plots except that they show the second-worst performance among the eight receivers, rather than the median. Figure 5-15 and 5-16 show the worst performance among the eight receivers.

Chapter 13 includes plots of these measurement results for the *individual receivers* along with extrapolations to D = D_{MIN} + 1 dB. Chapter 15 presents plots of the measurements and extrapolations for median, second-worst, and worst performance among the receivers. Appendix A includes tabulations of some of the data.

EARLIER-GENERATION RECEIVERS

A limited set of interference rejection tests was also performed on two earlier-generation receivers for purposes of identifying tuner type, as described in Chapter 3. The receivers are designated G3 and P1. These two DTVs would be classified as fourth-generation or earlier based on their multipath performance, which was tested as part of the SHVERA Study. Both were on the market in 2005, though P1 was actually introduced to the market in 2004.

Data from those measurements was plotted in Figure 3-7, but Figure 5-17 shows the same measurements overlaid with the median and range of measurements of the eight fifth-generation receivers, for comparison. All measurements were made with a desired signal power of -68 dBm; the third/fourth generation measurements were limited to channel offsets of N+2 through N+16.

It can be seen that the measurements on receiver P1 fall within the range of performance for the fifth-generation receivers except at two points: N+2, where the results for P1 are slightly better than any of the fifth-generation results, and N+10, where the results for P1 are worse than the fifth-generation results but are still within the ATSC A/74 guidelines.

On the other hand, most of the measurements on receiver G3 correspond to worse performance than any of the tested fifth-generation receivers, and most fall well outside of the ATSC A/74 guidelines. Given the small number of receivers tested, it is impossible to say whether similarly poor performance is common among earlier-generation receivers.

TABOO EFFECTS AND OTHER OBSERVATIONS

Some of the interference susceptibilities that can be seen in the plots were expected based on previous knowledge of the analog UHF taboos.[*] For example, in Figures 5-1 and 5-9, an increased susceptibility to interference can be seen at channels N+14 and N+15 in seven of the eight fifth-generation receivers; a similar peak is seen for one of the two earlier generation receivers in Figure 5-17. The mixer image frequency band,[†] which is centered 88 MHz (14 $^{2}/_{3}$ channels) above the center of the desired channel, straddles channels N+14 and N+15—causing the increased susceptibility to interference from undesired signals on those channels.

Similarly, a peak in susceptibility can be seen at N+7 in nine of the ten receivers. The analog taboo at N+7 exists primarily because of the possibility that unintentional local oscillator radiation from one TV receiver might interfere with reception on another TV tuned seven channels higher. Since all tests for this report were performed with only one TV turned on at a time, local oscillator radiation was not a factor.

Another potential explanation for the N+7 peak was the possibility that an undesired signal on channel N+7 could beat with the desired signal—creating interference that could pass through the IF filter of the receiver. This "IF beat" effect[‡] has previously been recognized with analog TV receivers and was initially thought to be the explanation of the N+7 peak observed here—both because of its location (at N+7) and the fact that the susceptibility threshold exhibits more of a constant undesired signal level rather than a constant D/U ratio (see, for example, Figures 5-11 and 5-12). The mixing product between the desired signal and an undesired signal would be expected to have a power level that is directly

[*] Taboos are channel spacings at which analog TV reception is vulnerable to interference. The taboos limited the allotment of local analog channel assignments.

[†] Mixer image for a single-conversion tuner occurs at a separation of twice the intermediate frequency (IF) above the center of the desired channel. The IF for single-conversion TV receivers is 44 MHz.

[‡] Young-Jun Chong, and others, "The design and implementation of TV tuner for digital terrestrial broadcasting." Consumer Electronics, 2000. ICCE. 2000 Digest of Technical Papers. International Conference on Consumer Electronics (ICCE), 2000 Digest of Technical Papers, 13-15 June 2000, p. 40 – 41.

proportional to both the desired signal power and the undesired signal power. The resulting interference passing through the receiver's IF filter would thus increase in direct *proportion to the desired signal power, so that once the undesired signal reaches a sufficient level to result in the interference coming* within about 15 dB of the desired signal power, reception would no longer be possible; attempts to re-establish reception by increasing the desired signal power would result in corresponding increases in the interference power.

Tests results presented in Chapter 7 contradict the IF-beat explanation for the N+7 peak—suggesting instead some sort of direct interaction between the TV's local oscillator and the undesired signal. The absence of an N-7 peak also runs counter to the IF-beat explanation.

Another analog taboo is associated with the "half IF" beat response. This is the result of the second harmonic of an undesired signal, spaced above the desired channel by half the IF frequency, beating with the second harmonic of the TV's local oscillator. The result is an increased susceptibility to interference spaced 22 MHz (3 $^{2}/_{3}$ channels) above the center of the desired channel. The susceptibility peak from this effect would be expected to be seen primarily at channel N+4. Peaks at N+4 were observed on only two receivers: A3 (Figure 5-3) and G3 (Figure 5-17).

An unexpected sensitivity occurred at N-6 on some receivers. Receiver J1 exhibits a large peak at N-6, as seen in Figure 5-1. A smaller peak can be seen for receiver N1 in the same graph, and a third receiver (A3) exhibits a slight susceptibility peak in Figure 5-3. The cause of this sensitivity is not known.

Also unexpected is that two of the receivers (J1 and N1) are significantly more susceptible to interference on the second-adjacent channels (N-2 and N+2) than on the first-adjacent ones (N-1 and N+1), and one more receiver (O1) exhibits such behavior on the positive side (i.e., N+2 only). (See Figure 5-1, for example.) In fact, at low signal levels (D_{MIN} + 3 dB), the second adjacent channels are as susceptible to interference as the first adjacent channels even when viewed on a median basis across all eight TVs. (See the lower curve on Figure 5-12, for example.)

Some broader band effects can also been seen. For example, in Figure 5-3, the susceptibility of receiver D3 to interference is seen to smoothly decrease from N-4 to N-16. The absence of peaks at specific channels suggests that this is a cross-modulation effect. Cross-modulation creates an interference power that is directly proportional to the desired signal power. As a result, it is expected to exhibit a fixed undesired signal level threshold that does not change as the desired signal decreases (until desired signal approaches D_{MIN}). In Chapter 13 (Figure 13-4), we see that this is indeed the case at desired signal levels of -53 dBm and below. The smooth decrease in the cross-modulation effect as the desired signal moves from N-4 to N-16 is likely to be a result of rolloff caused by the RF tracking filter in the receiver.

This apparent cross-modulation effect on receiver D3 exhibits some rather unexpected behavior as the undesired signal moves from channel N-4 to N-3. With a desired signal power of -53 dBm, the interference susceptibility, which had been rising smoothly as the undesired signal was moved closer to the desired channel, suddenly drops precipitously at channel N-3 by 20 dB or more* and remains lower at channels N-2, N-1, N+1, and N+2 than it had been at N-4. We believe that the reduction in susceptibility is due to the influence of the undesired signal on the receiver's automatic gain control (AGC)—a topic that will be discussed further in Chapters 8 and 11.

Though the "hardness" of the thresholds was not one of the measurement parameters for this study, we noted a strong "cliff effect" in most of the threshold measurements. For example, in most cases, increasing interference level about 1 dB above the threshold of visibility (TOV)—the point at which picture degradation becomes perceptible—caused complete loss of picture. In some cases picture loss didn't occur until the undesired signal level rose as much as much as 3 dB and in one case, 5 dB (though

* The susceptibility drops below the measurement floor of the test setup.

picture errors occurred continuously in that case after only a 1.5 dB increase). In a few cases, picture loss occurred concurrently with appearance of errors or with only an additional 0.1 dB increase in interference—an extremely abrupt cliff!

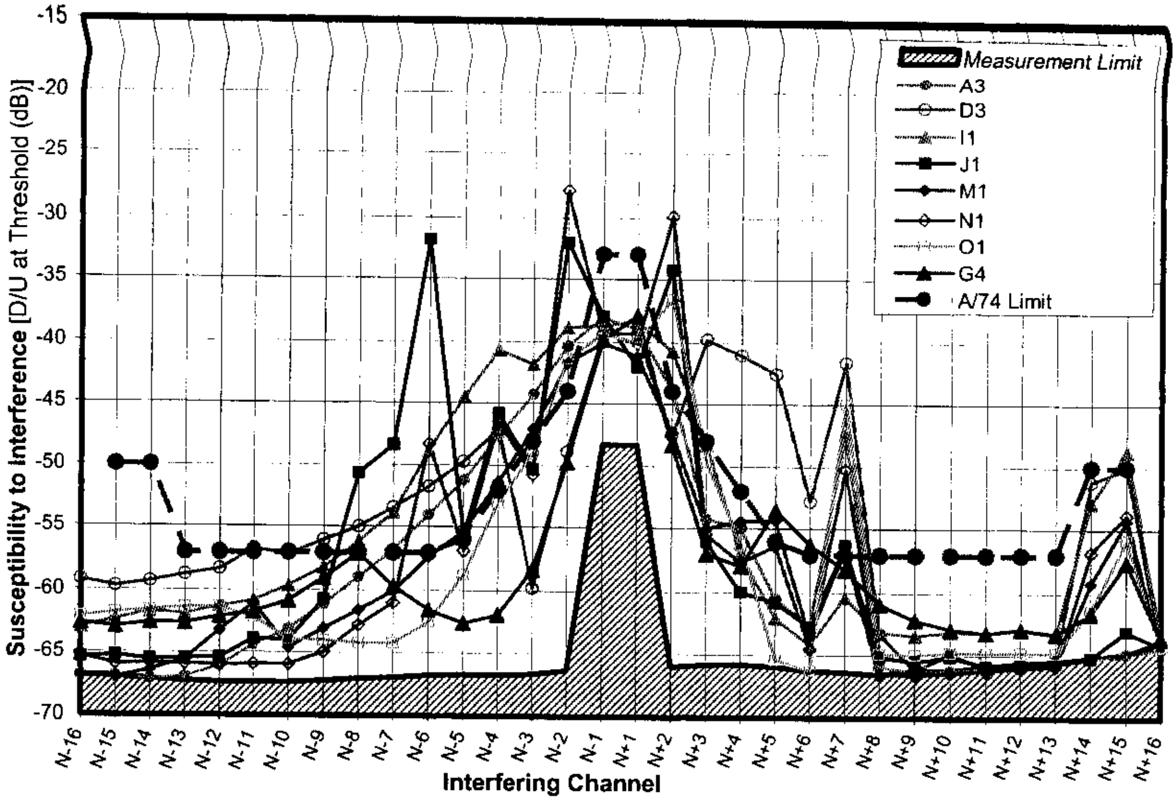

Figure 5-1. D/U of 8 Receivers at D = -68 dBm on Channel 30

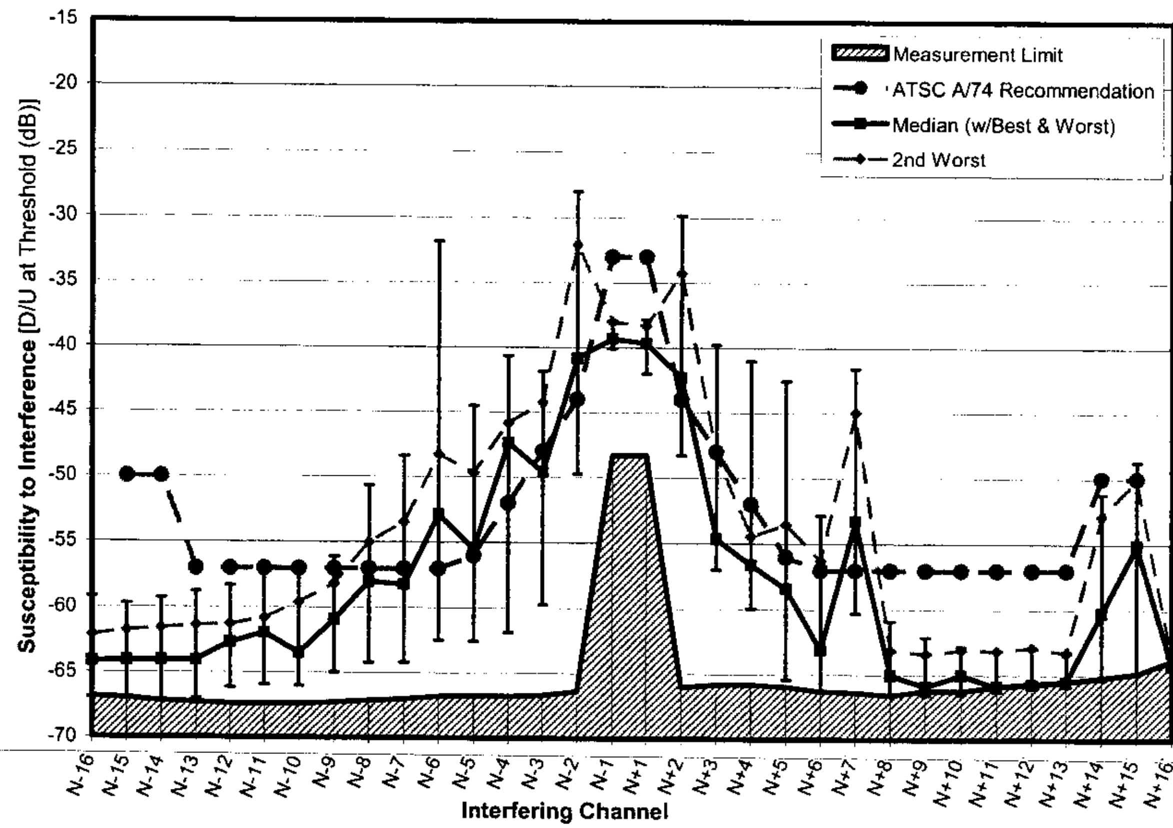

Figure 5-2. D/U Statistics at D = -68 dBm on Channel 30

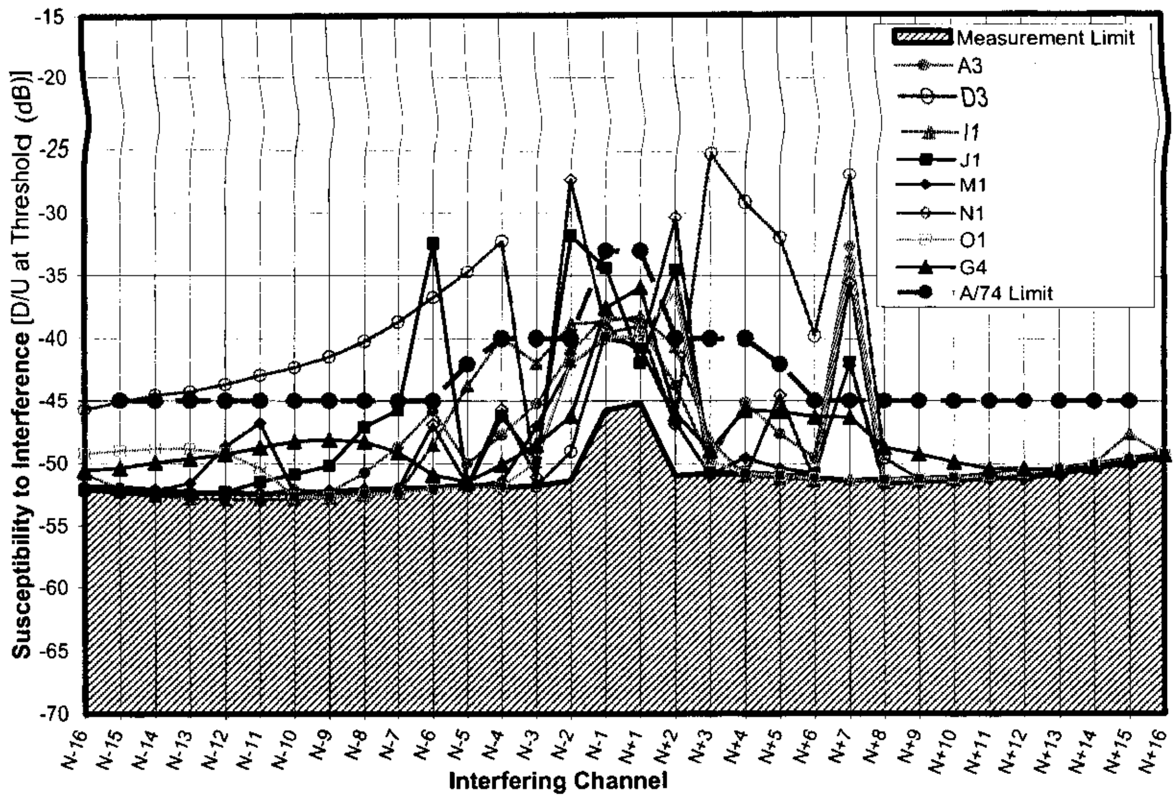

Figure 5-3. D/U of 8 receivers at D = -53 dBm on Channel 30

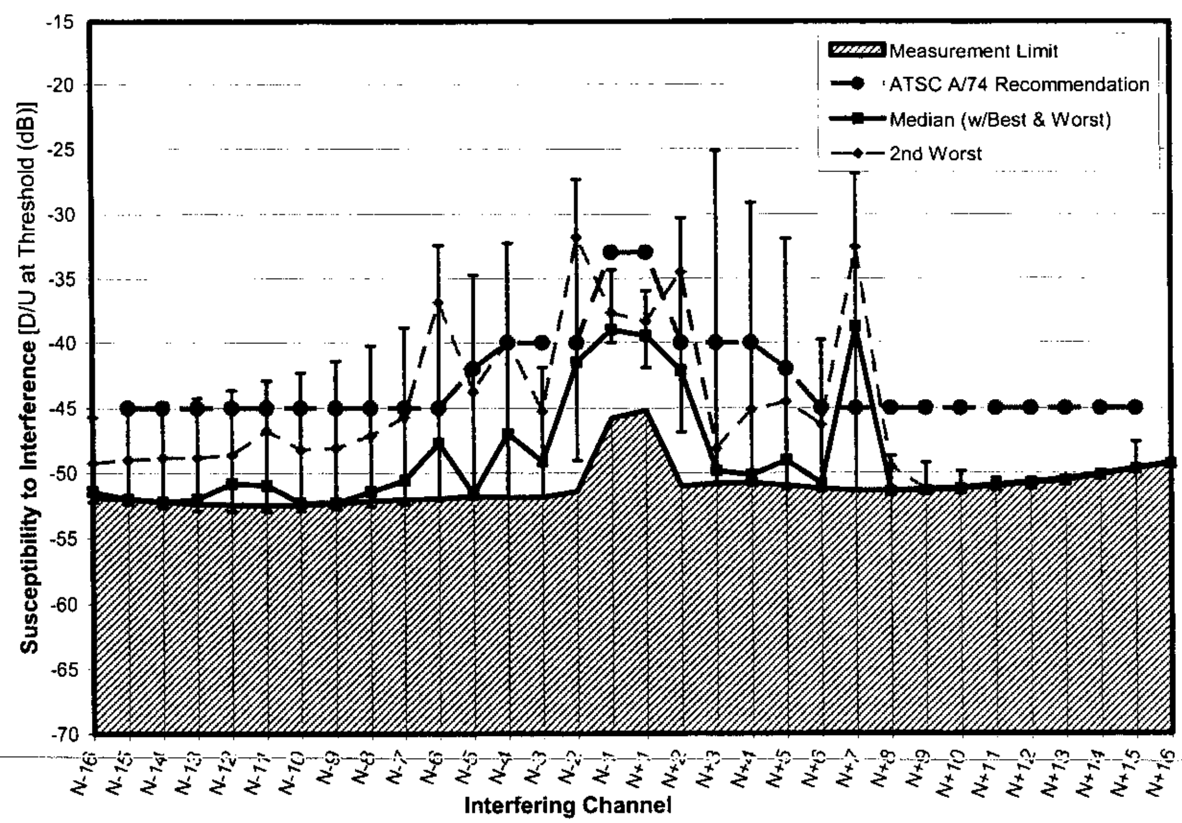

Figure 5-4. D/U Statistics at D = -53 dBm on Channel 30

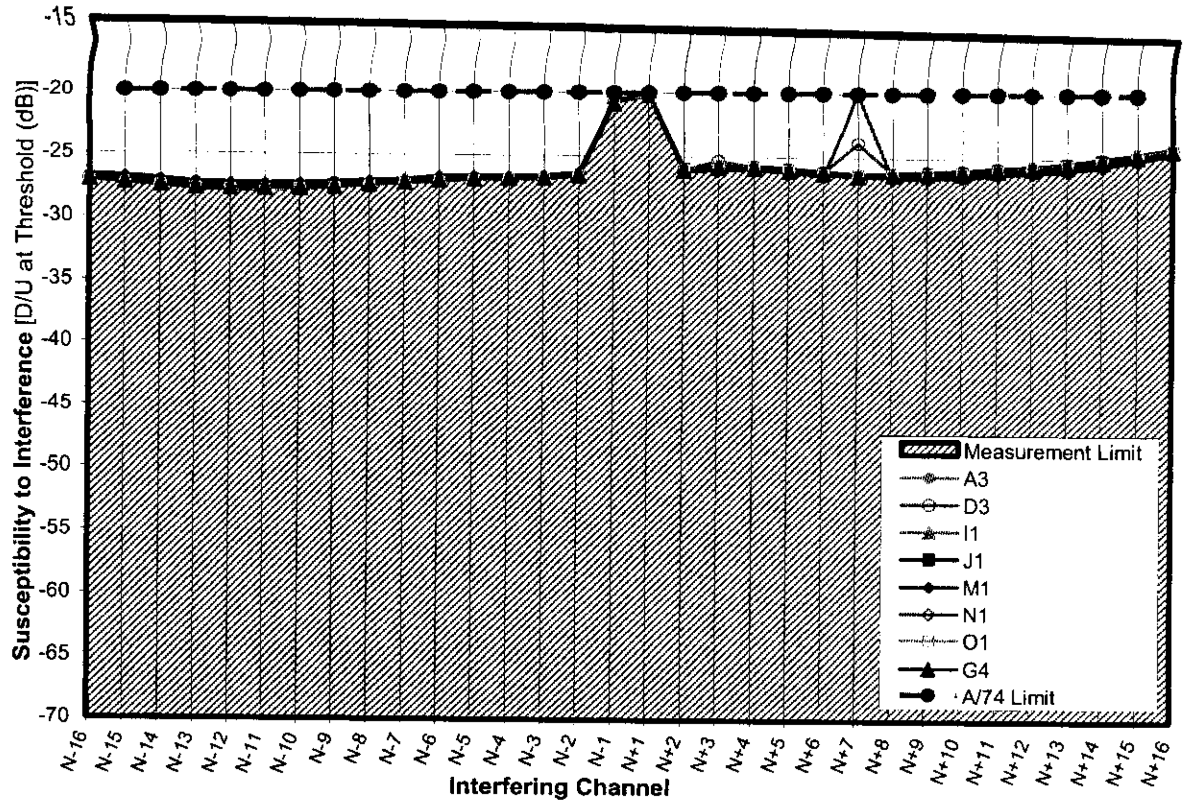

Figure 5-5. D/U of 8 receivers at D = -28 dBm on Channel 30

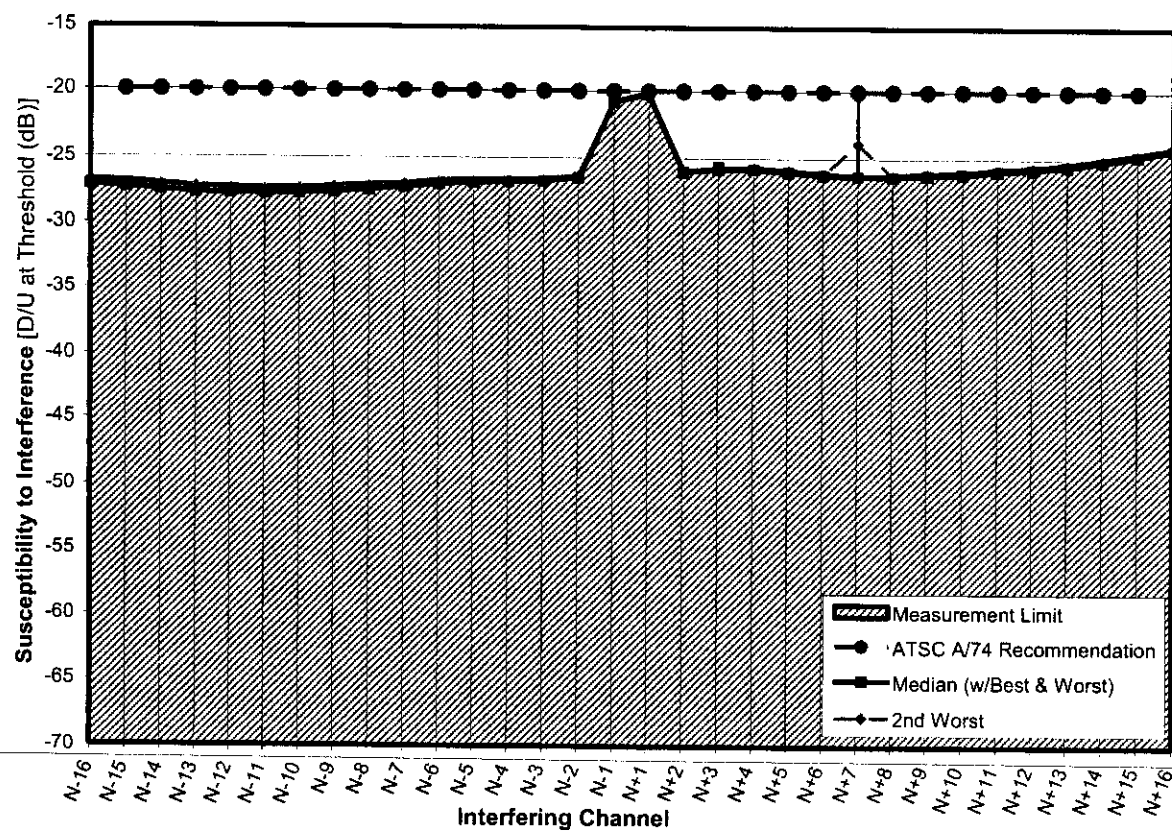

Figure 5-6. D/U Statistics at D = -28 dBm on Channel 30

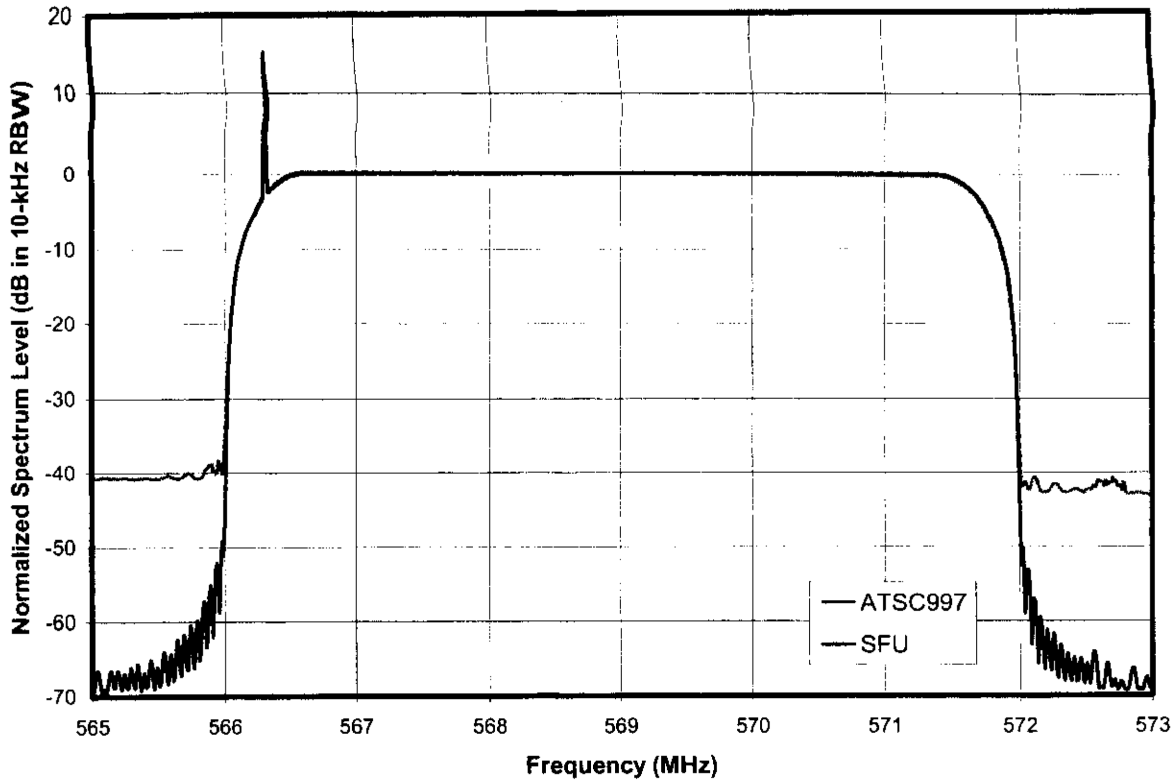

Figure 5-7. Spectra of Two Desired Signal Sources

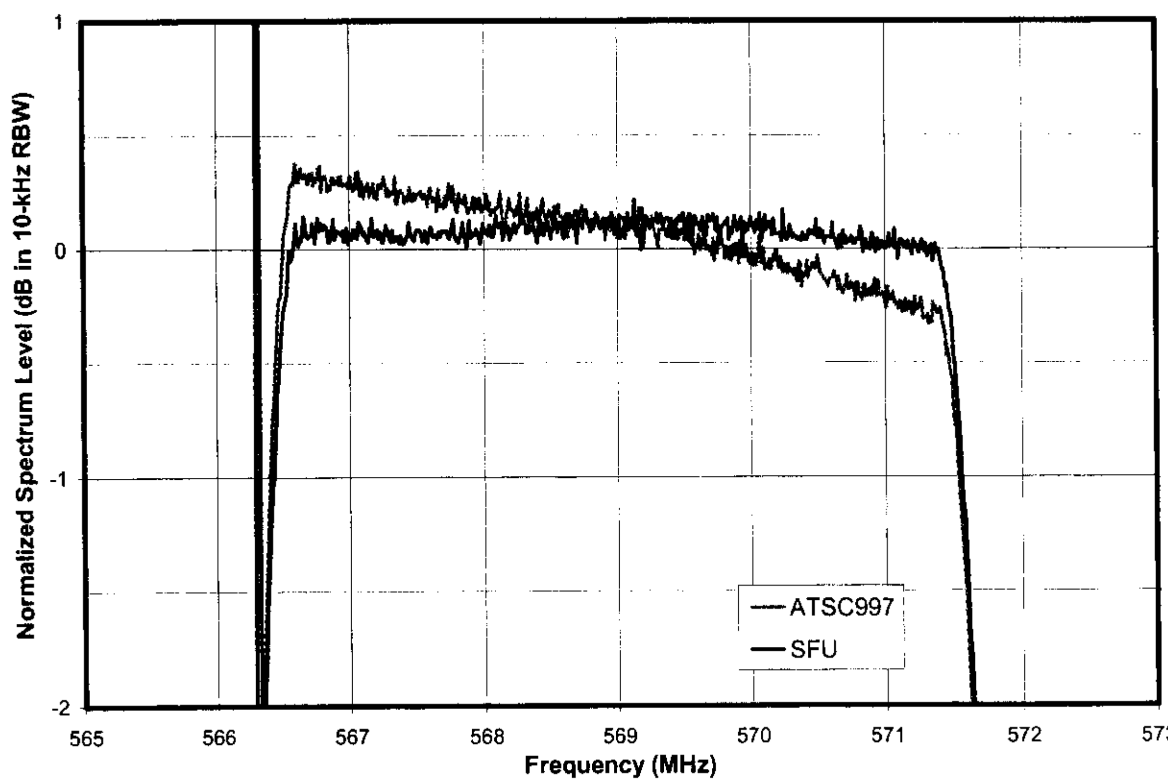

Figure 5-8. Spectra of Two Desired Signal Sources on Expanded Scale

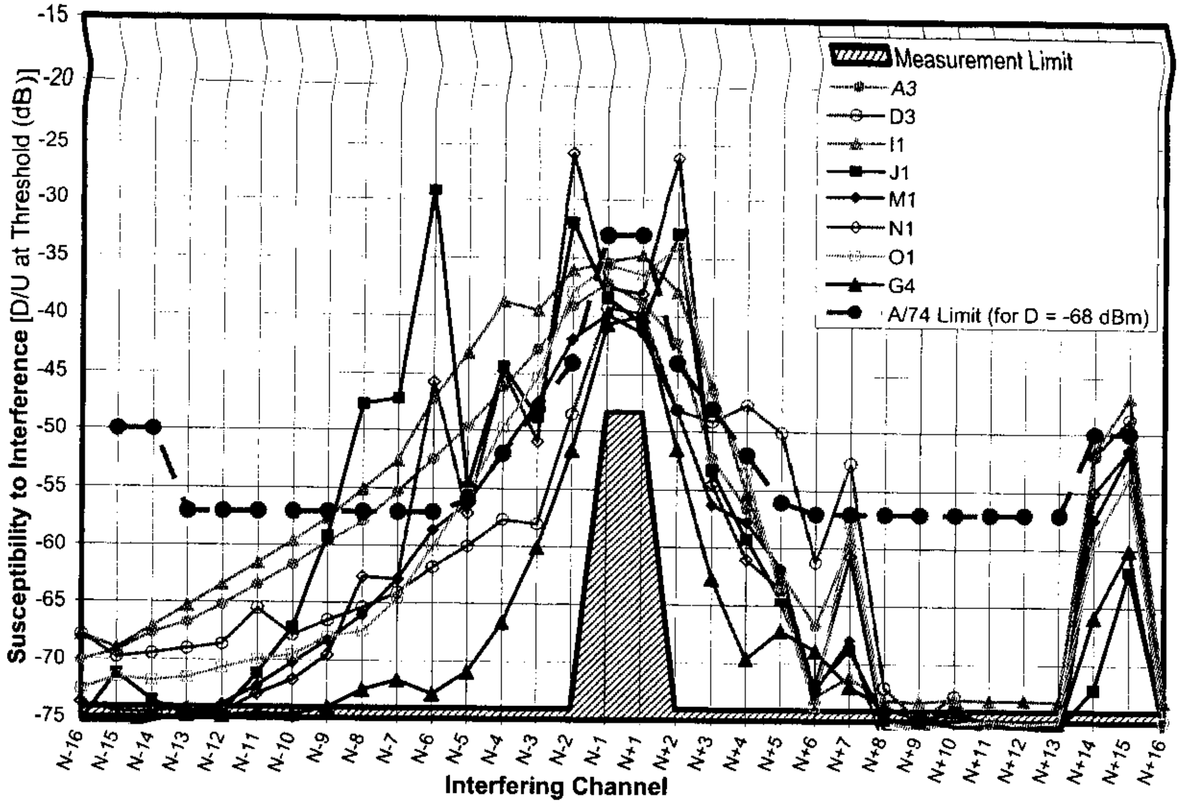

Figure 5-9. D/U of 8 receivers at D = D_{MIN} + 3 dB on Channel 30

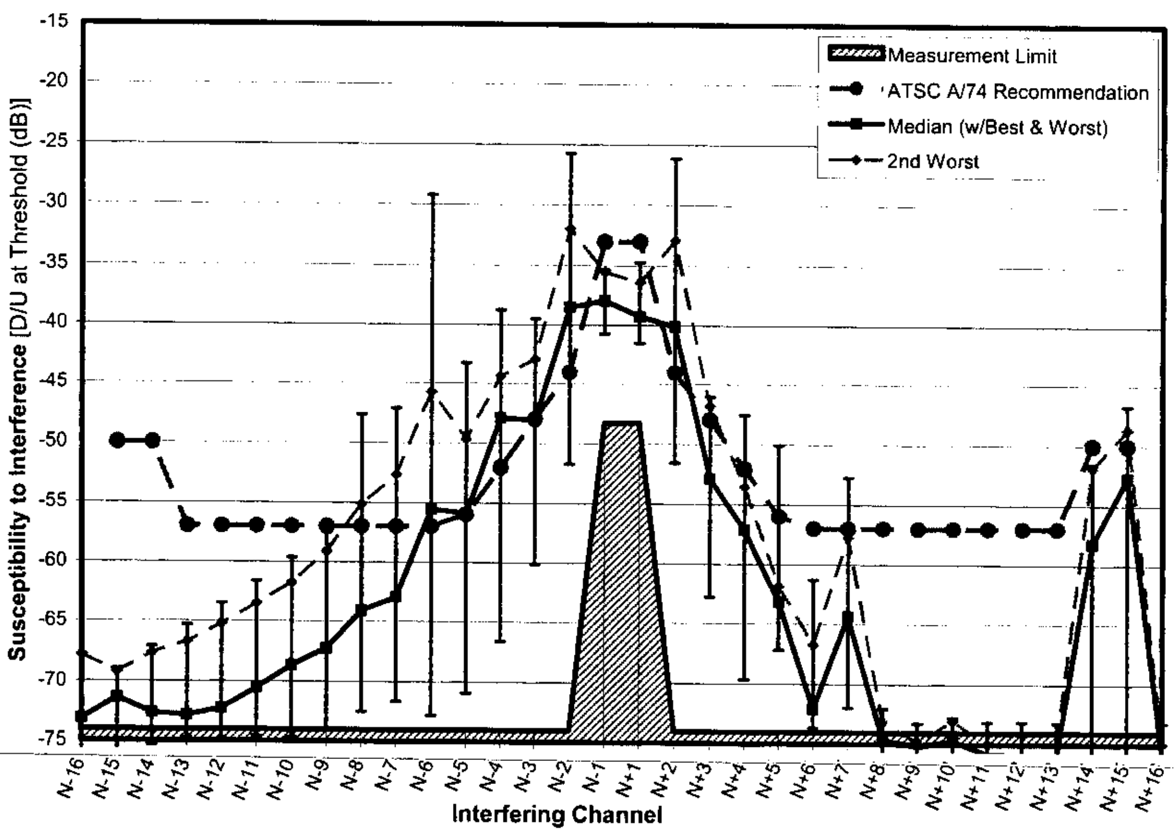

Figure 5-10. D/U Statistics at D = D_{MIN} + 3 dB on Channel 30

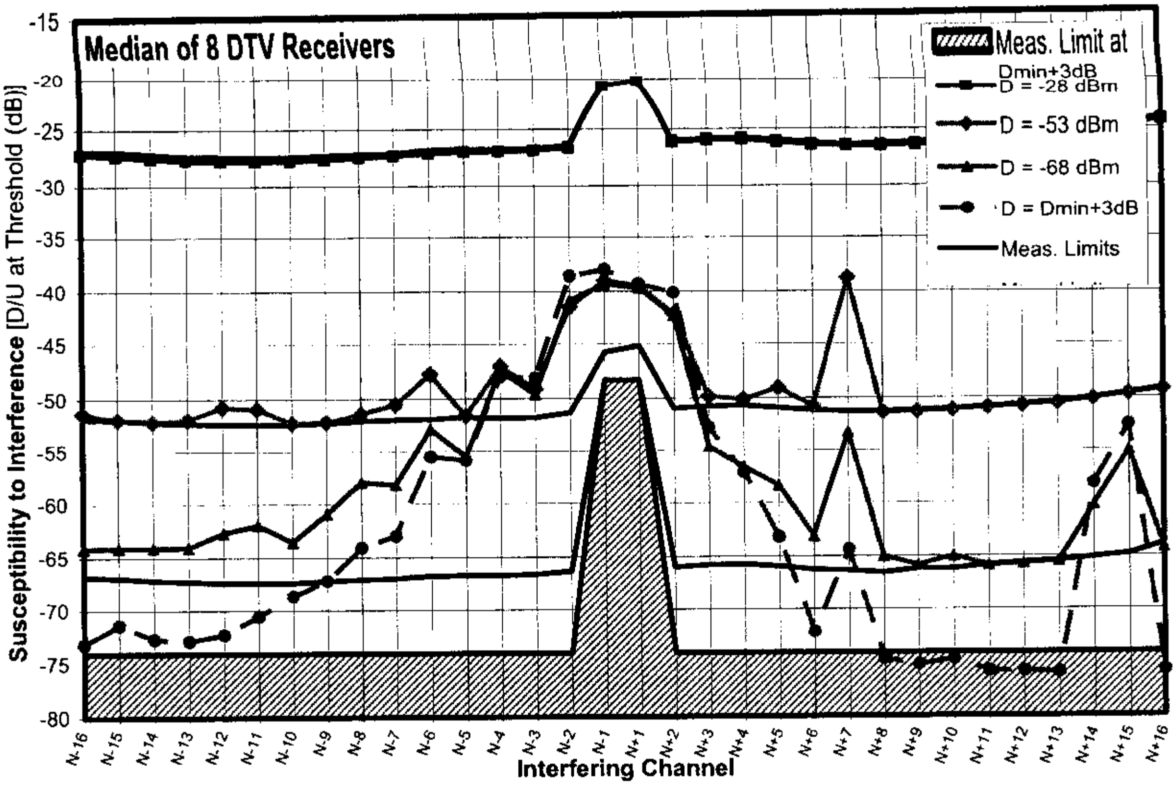

Figure 5-11. Median D/U of 8 receivers at Four Signal Levels on Channel 30

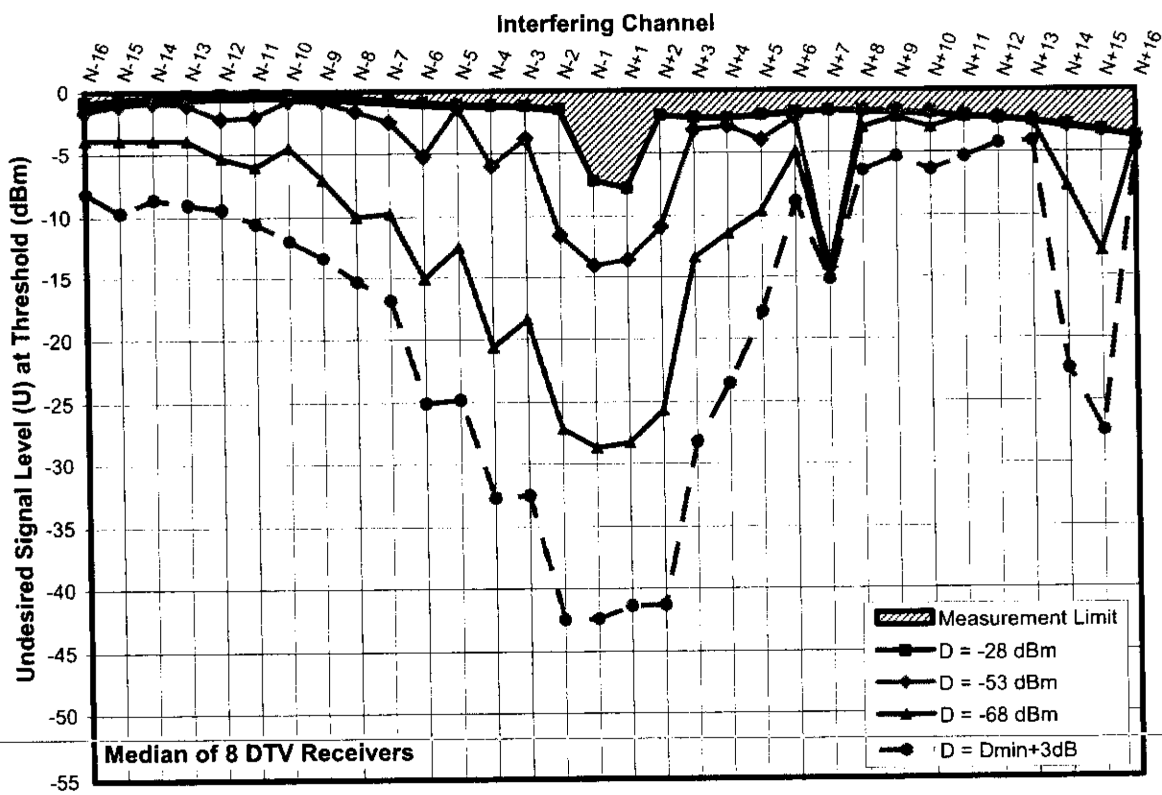

Figure 5-12. Median Threshold U of 8 receivers at Four Signal Levels on Channel 30

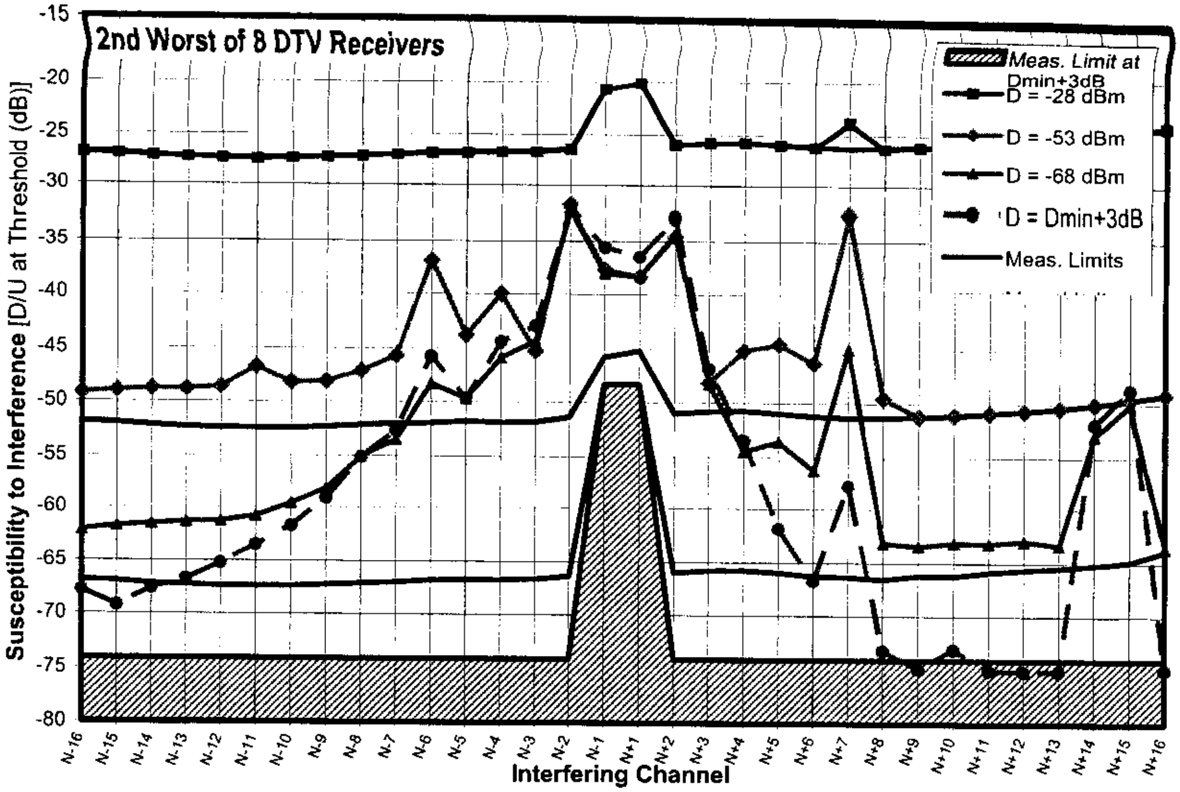

Figure 5-13. 2nd Worst D/U of 8 receivers at Four Signal Levels on Channel 30

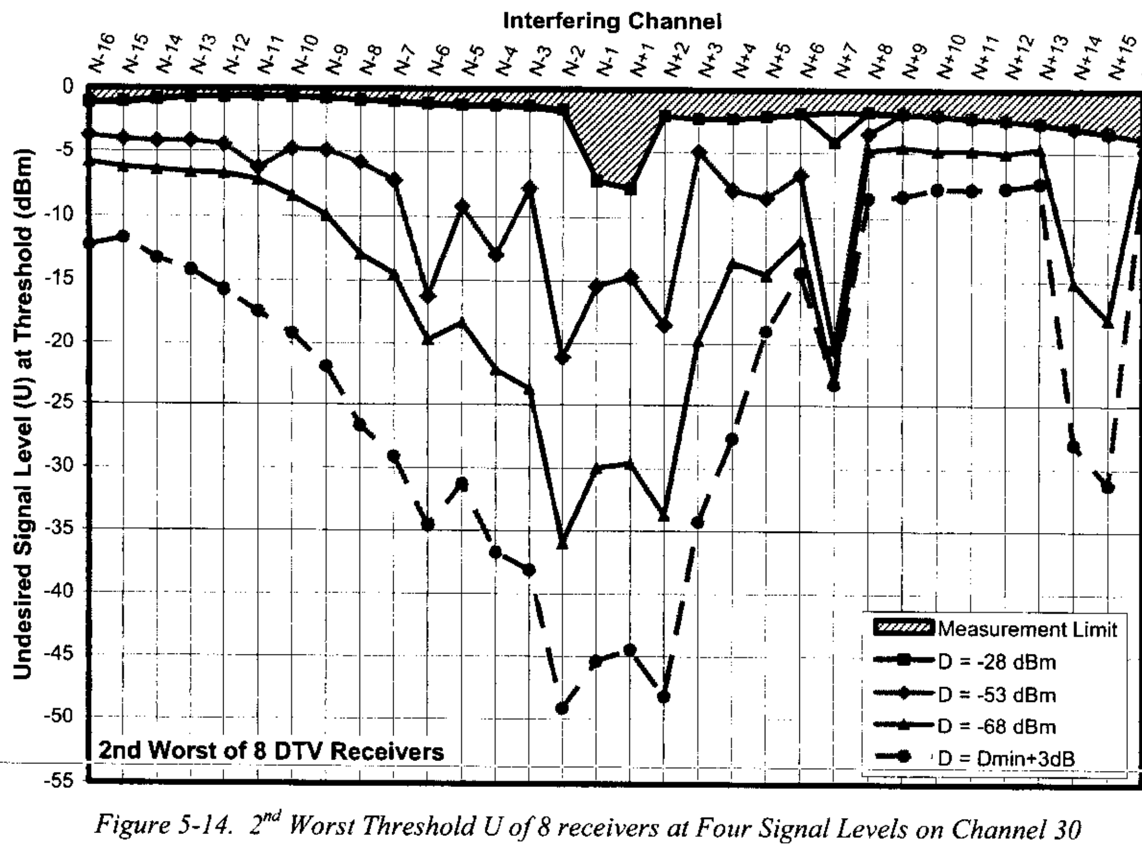

Figure 5-14. 2nd Worst Threshold U of 8 receivers at Four Signal Levels on Channel 30

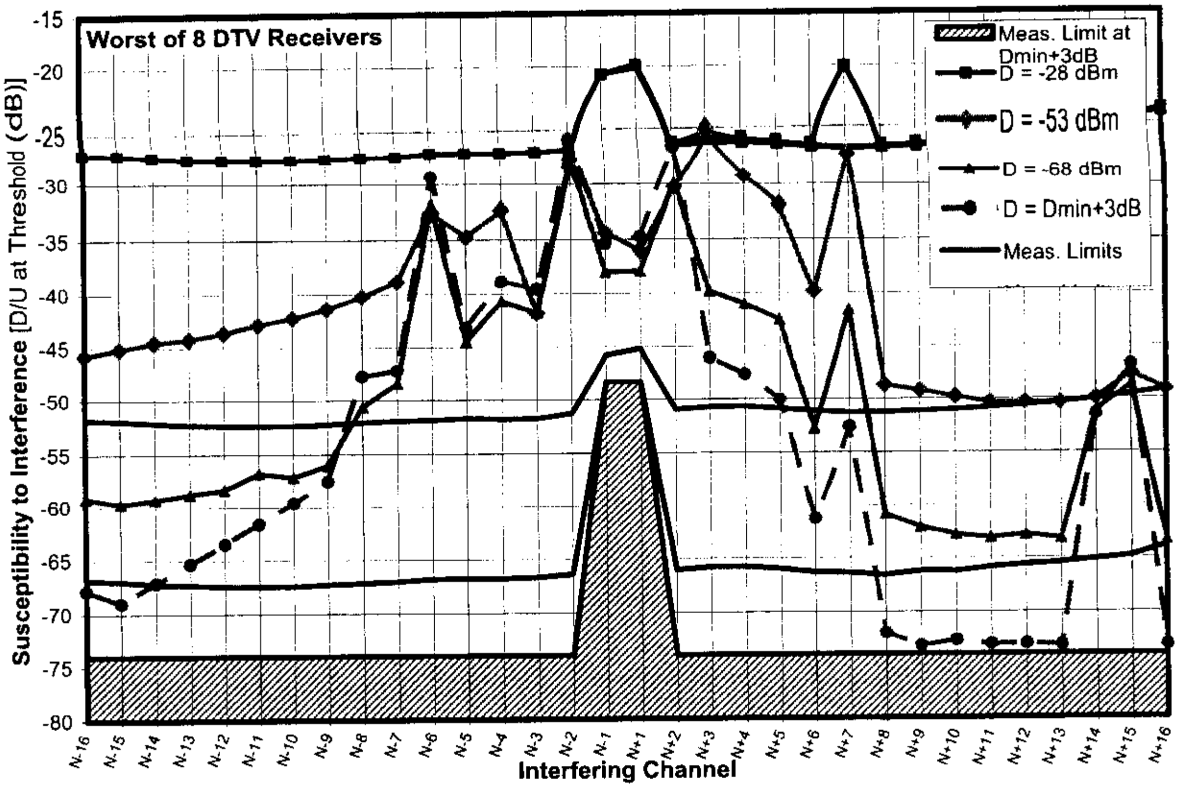

Figure 5-15. Worst D/U of 8 receivers at Four Signal Levels on Channel 30

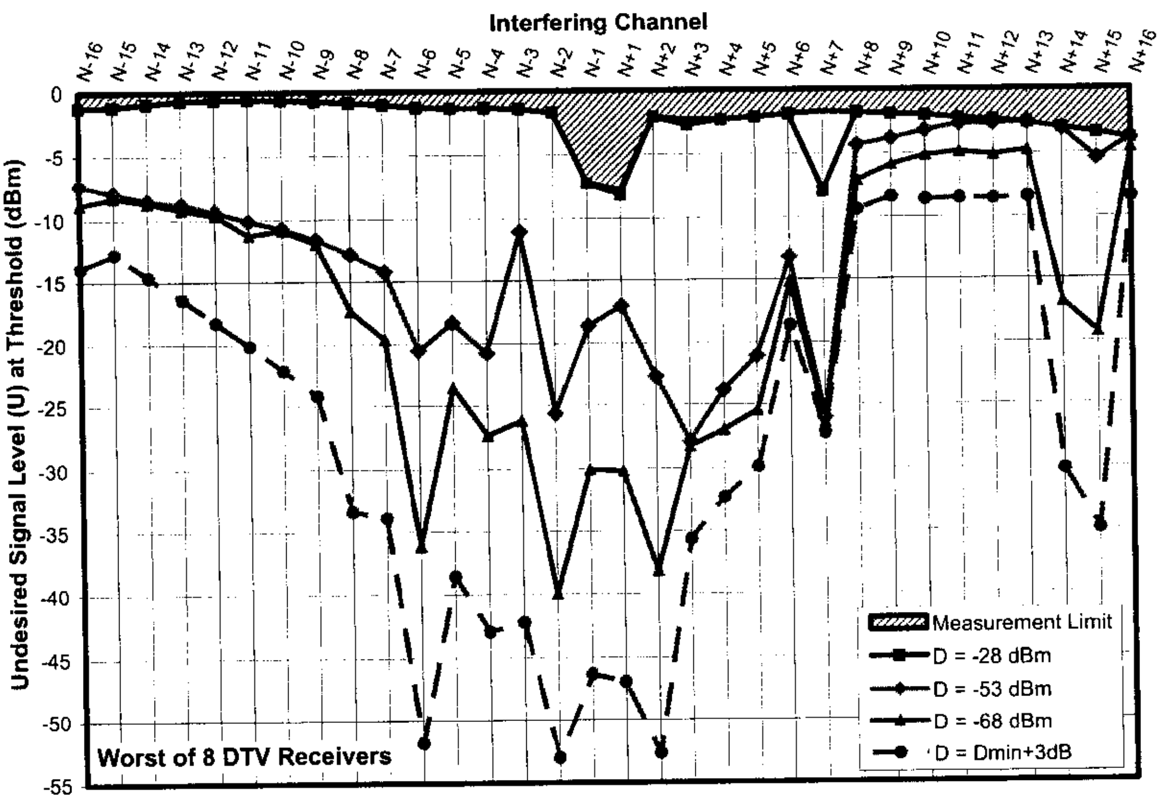

Figure 5-16. Worst Threshold U of 8 receivers at Four Signal Levels on Channel 30

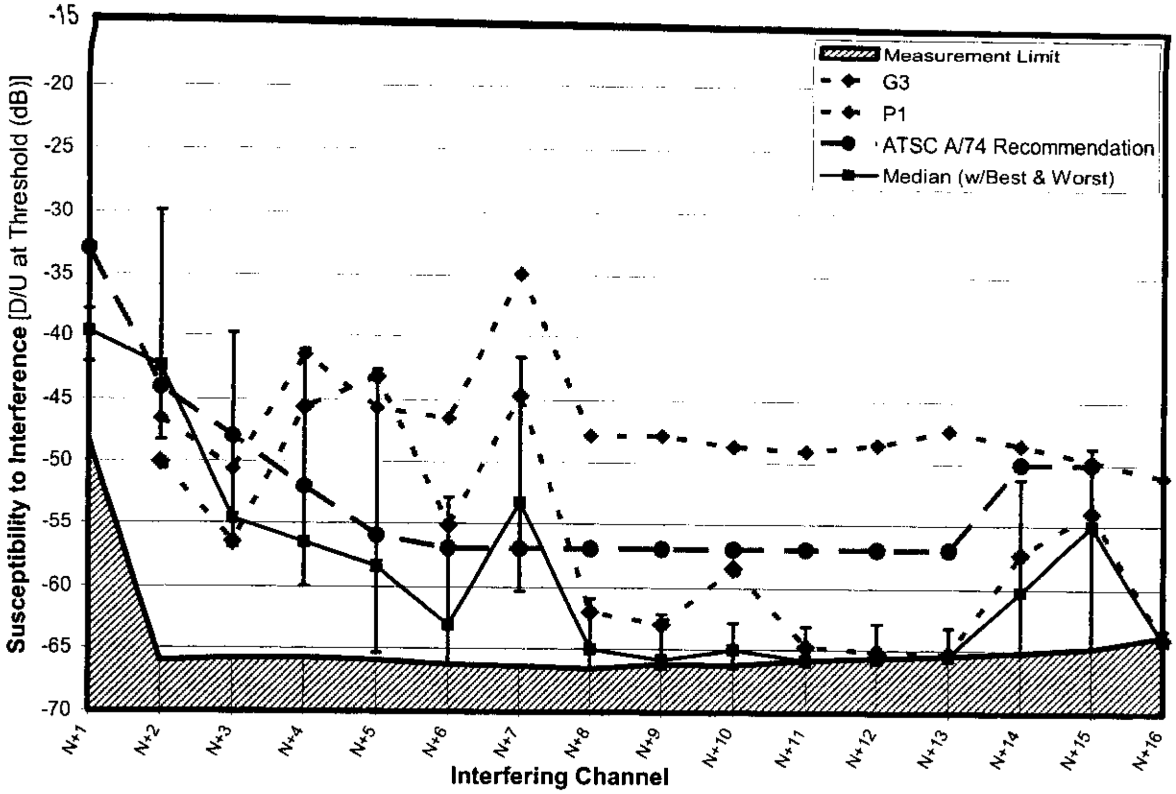

Figure 5-17. D/U of Two Earlier-Generation Receivers at D = -68 dBm Relative to Fifth-Generation Results

CHAPTER 6
REJECTION RESULTS ON CHANNEL 51 FOR SINGLE 8-VSB INTERFERERS

This chapter presents the results of interference rejection tests of seven DTV receivers tuned to channel 51. The interferer for these tests was an 8-VSB signal placed sequentially on channels N+1 through N+16. The tested receivers comprise seven of the eight receivers that were tested for Chapter 5. Tests on one of the seven receivers were not completed due to equipment failure. (Note that presentation of detailed test results showing the variation of D/U with desired signal level for one TV receiver at channel 51 are postponed until Chapter 11.)

The channel-51 tests for this chapter occurred chronologically before those on channel-30, described in Chapter 5. The primary focus of these tests was to investigate interference susceptibility of DTV receivers operating in the upper UHF core channels to interference from future services to be offered in spectrum currently assigned to television channels 52 through 67. Because of this focus, tests were limited to undesired signals above the desired channel.

Notwithstanding the above focus, an 8-VSB source was used as the undesired signal for all of these tests (unlike the tests in Chapter 5, which used an 8-VSB source only at N-1 and N+1 and used a bandlimited Gaussian noise source at all other channel offsets).* That choice was based on the steep rolloff of the 8-VSB source at its channel edges and the lack of availability of surrogate devices representative of signals planned for use in channels 52 through 67.

TESTS AT ATSC-SPECIFIED DESIRED SIGNAL LEVELS

"Weak" Desired Signal (D = -68 dBm)

Figure 6-1 shows measured values of D/U ratios at TOV for seven DTV receivers for undesired signal channels ranging from N+1 to N+16 with the desired signal power set to -68 dBm, the signal level that the ATSC designates as "weak". The configuration of the plots is similar to those in Chapter 5, except for the single-sided range of channel offsets, so the reader is referred to the corresponding section of that chapter for further explanation of the format.

The ATSC-recommended DTV-into-DTV interference rejection thresholds are shown on the plot as a reference. Compliance with those voluntary limits would be indicated by all points on each measurement curve falling on or below the ATSC line. For the desired signal level of -68 dBm, only one of the receivers (M1) fully complies with the guidelines. Receiver D3 fails to comply at seven of the sixteen tested channel offsets. The other receivers fail to comply at from one to three of the channel offsets. The N+7 channel offset seems to offer the most challenge in that five of the receivers failed to comply with the guidelines at that offset. We note that these measurements are directly comparable to the ATSC performance guidelines since they were made with an 8-VSB signal as the undesired signal.

The measurements on the seven receivers for the first adjacent channel (N+1) are closely clustered, and all satisfy the ATSC guidelines. The second-adjacent channel results (N+2) are much more scattered—with three of the receivers failing to meet the ATSC guidelines and actually exhibiting more susceptibility to interference at N+2 than at N+1.

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* Failure of the 8-VSB source that had served as the undesired signal for these tests forced the use of the bandlimited Gaussian noise source for subsequent tests on channel 30.

Figure 6-2 shows the best, median, second worst, and worst performance at each channel offset. On a median basis the only failure to satisfy the ATSC recommended performance is at N+7.

<u>"Moderate" Desired Signal (D = -53 dBm)</u>

Figure 6-3 shows measured values of D/U ratios at TOV for the same seven DTV receivers with the desired signal power set to -53 dBm, the signal level that the ATSC designates as "moderate". None of the receivers comply with the performance guidelines at all channel offsets. Again, N+7 appears to be the most challenging channel offset in that six of the seven receivers failed to comply at that offset. Receiver D3 was, again, the poorest performer—failing to comply with the guidelines at five of the sixteen tested channel offsets. The other receivers failed to comply at one or two channel offsets.

Figure 6-4 shows the best, median, second worst, and worst performance at each channel offset. On a median basis the only failure to satisfy the ATSC recommended performance is at N+7.

<u>"Strong" Desired Signal (D = -28 dBm)</u>

Figure 6-5 shows that, with the desired signal set to the level that the ATSC designates as "strong", every receiver complied with the ATSC guidelines. Since the measurement limit was close to the ATSC guidelines, almost all of the measurements fell at the measurement limit (*i.e.*, the test setup was not capable of generating a strong enough undesired signal to cause interference.)

Figure 6-6 shows the corresponding statistical data.

COMPARISON TO CHANNEL-30 RESULTS

Figures 6-7 and 6-8 compare the median D/U measurements on channel 30 with those on channel 51 for desired signal levels of -68 dBm and -53 dBm, respectively, for the seven DTV receivers that were tested on channel 51. (Note that the medians for channel 30 shown in these two charts are for only seven receivers—in order to match the channel-51 test group. The channel-30 data in Chapter 5 includes an eight receiver.) The largest differences among points that were measurable were 5 dB at N+15 (mixer image frequency) and 4 dB at N+2; both of those measurements indicate better performance at channel 51 than at channel 30 (perhaps surprisingly). For all other measurements, the match between channels was within about 2 dB or less.

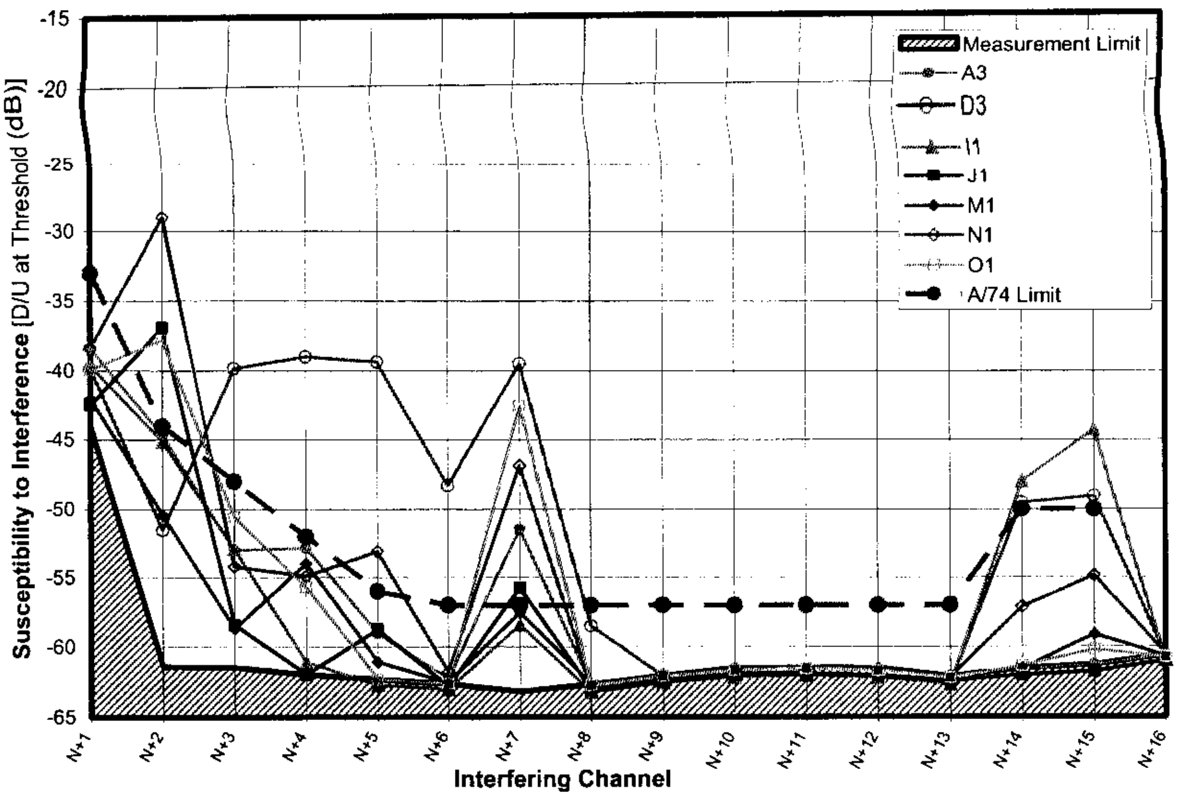

Figure 6-1. D/U of 7 Receivers at D = -68 dBm on Channel 51

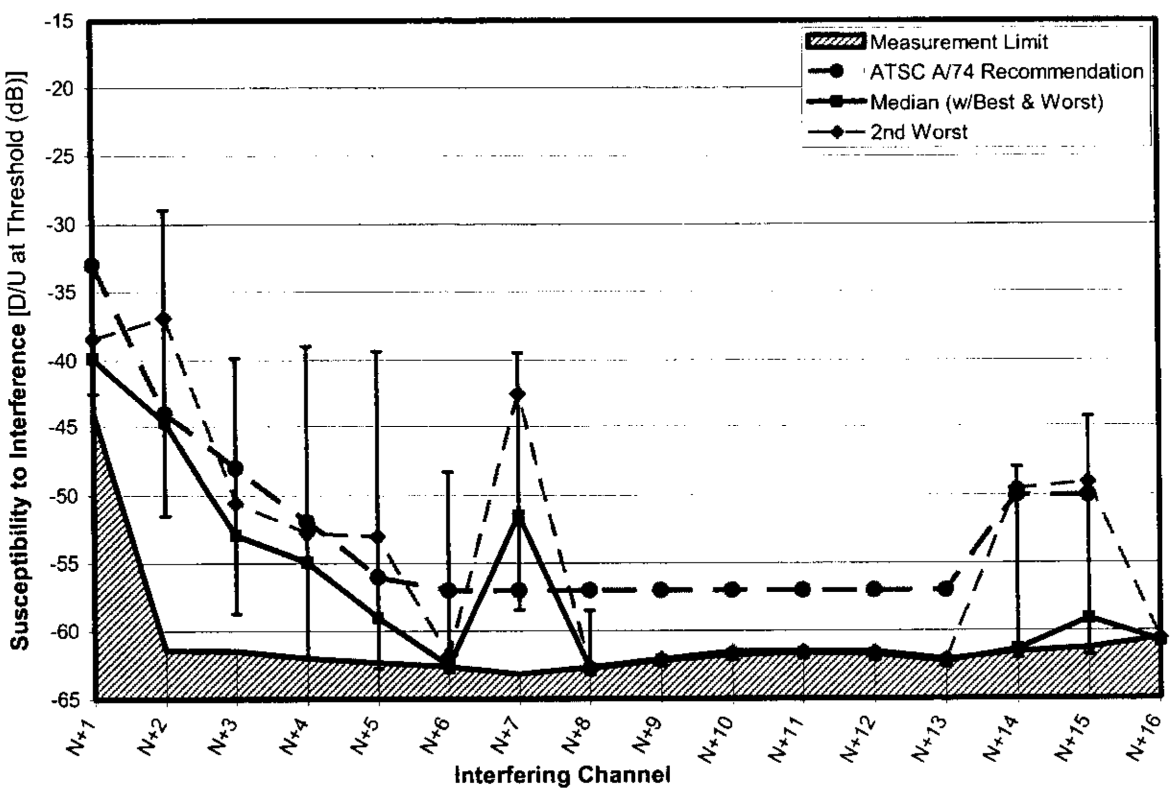

Figure 6-2. D/U Statistics at D = -68 dBm on Channel 51

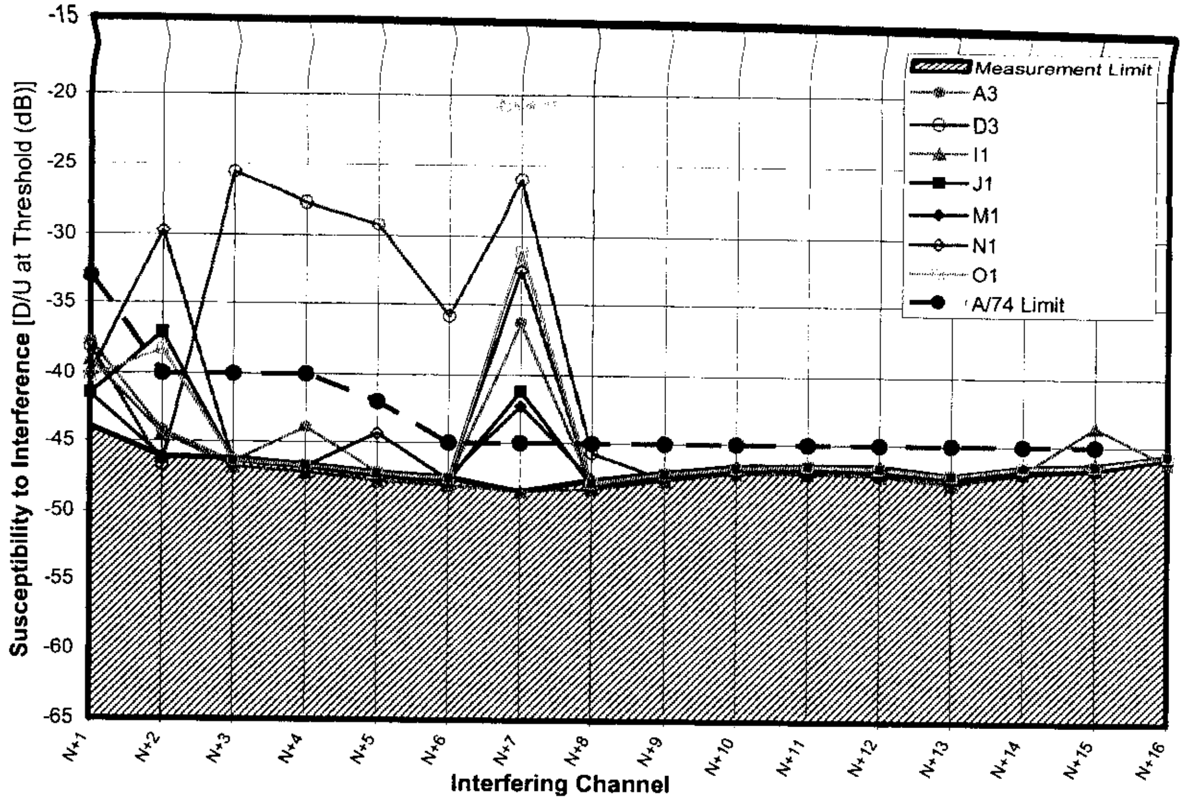

Figure 6-3. D/U of 7 Receivers at D = -53 dBm on Channel 51

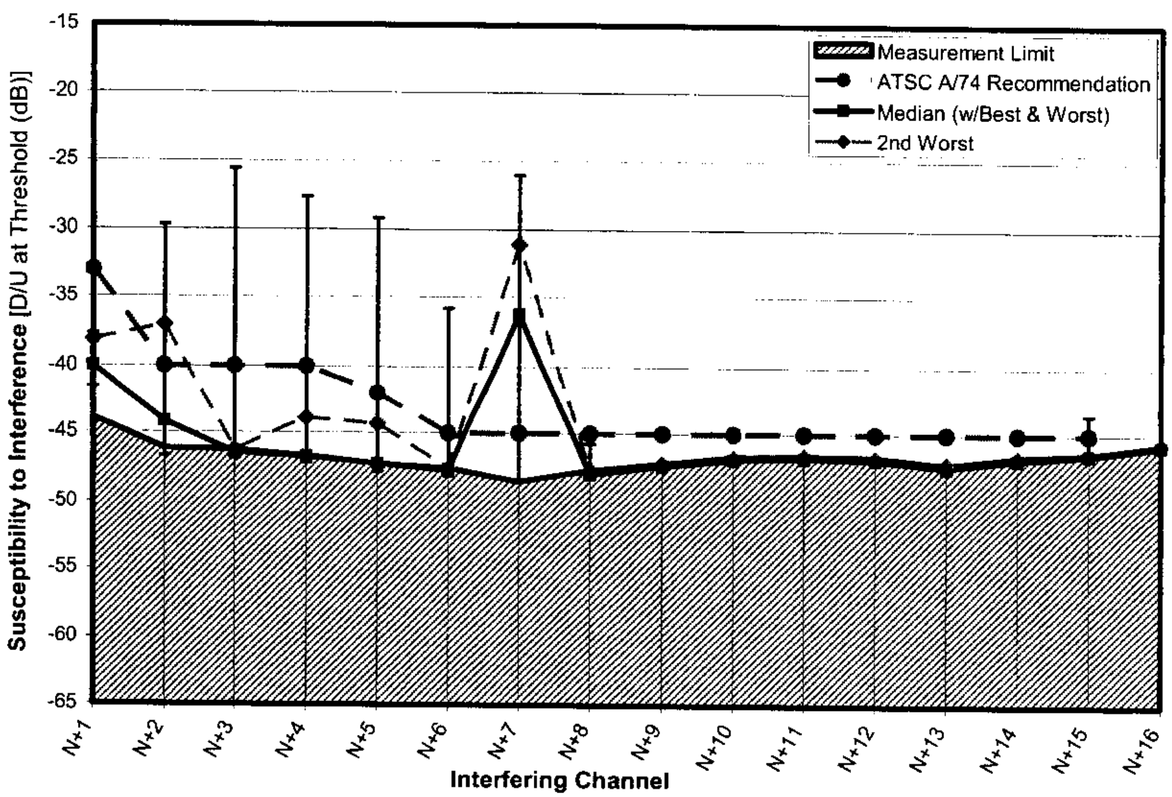

Figure 6-4. D/U Statistics at D = -53 dBm on Channel 51

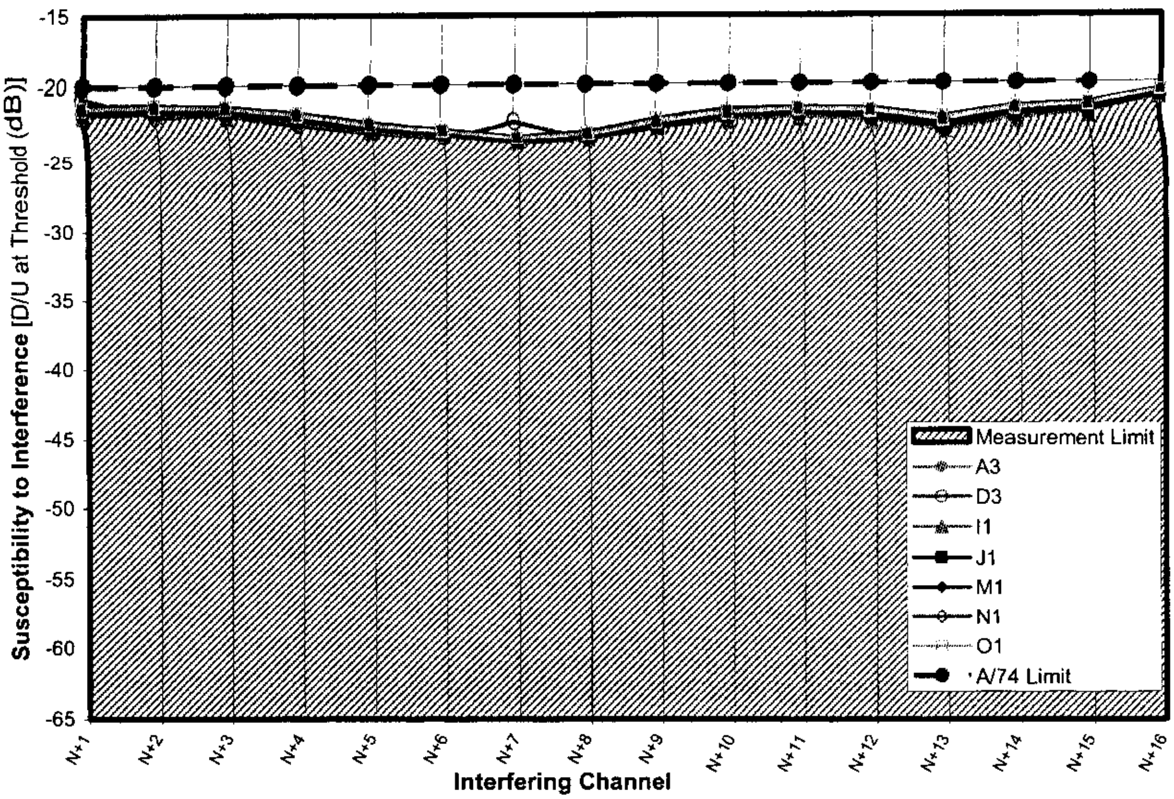

Figure 6-5. D/U of 7 Receivers at D = -28 dBm on Channel 51

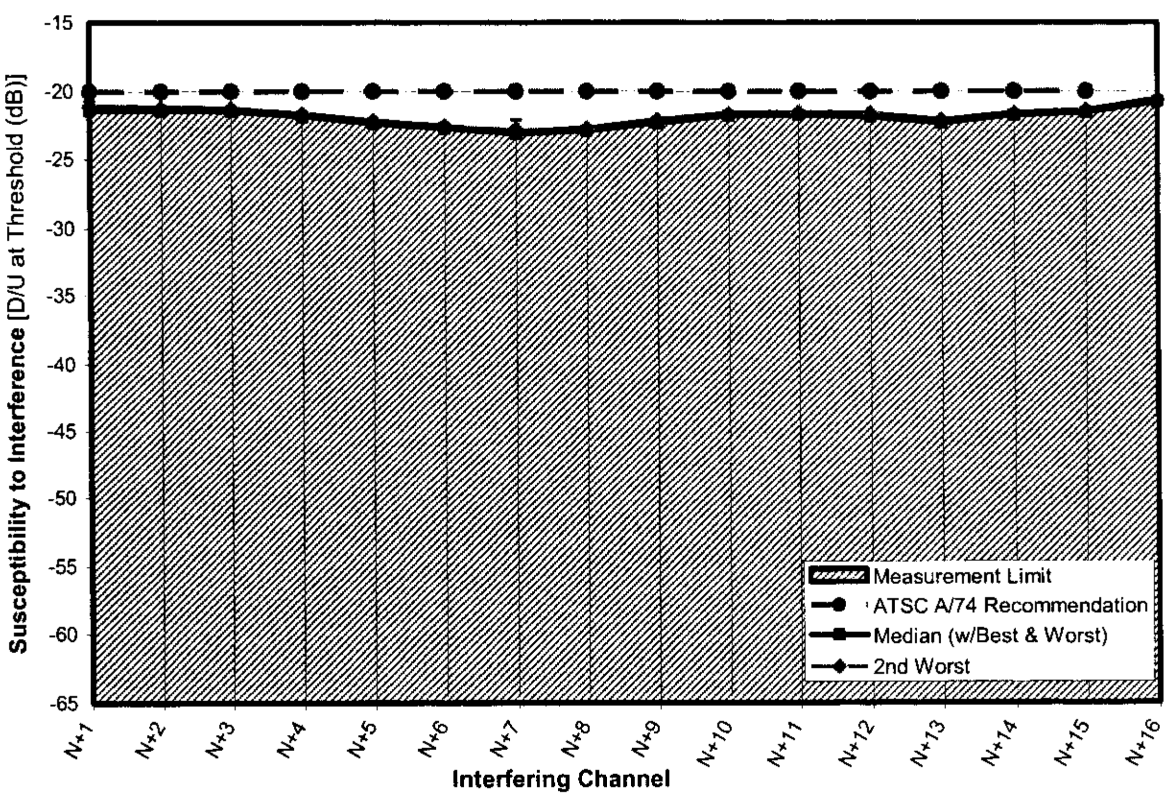

Figure 6-6. D/U Statistics at D = -28 dBm on Channel 51

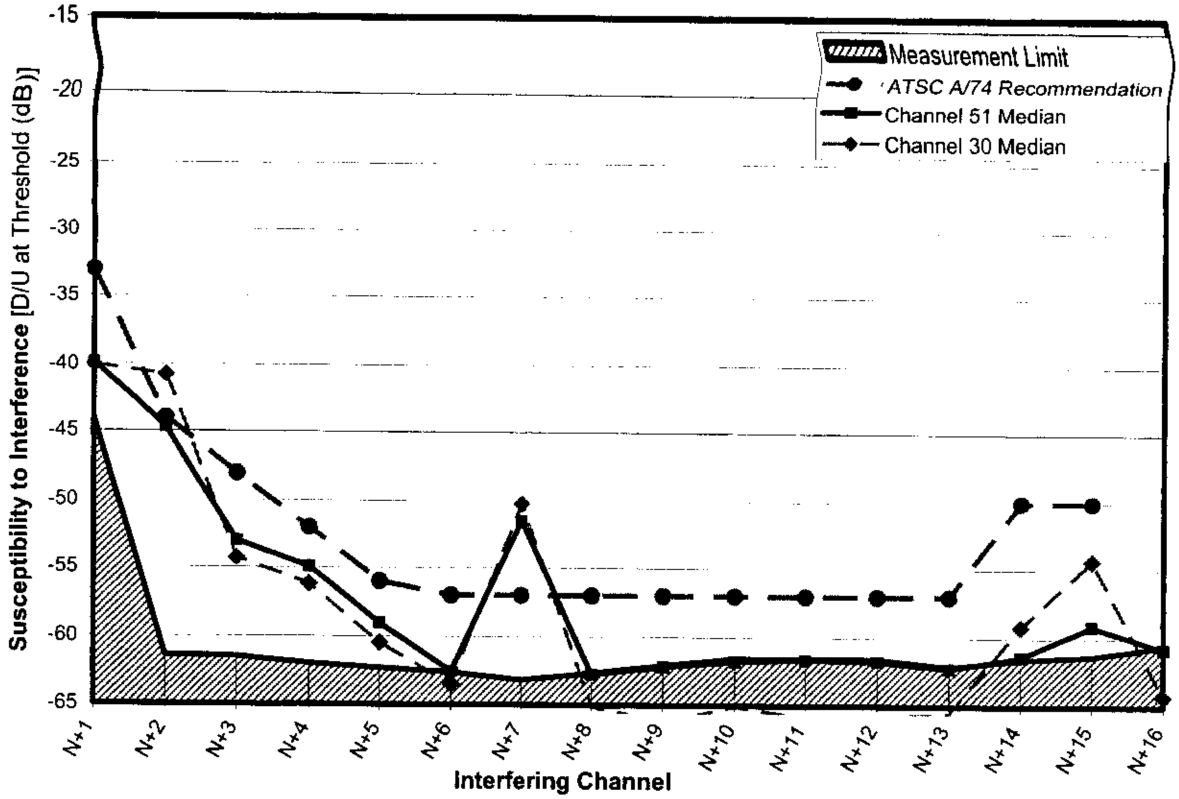

Figure 6-7. Comparison of Median D/U for 7 Receivers on Channels 30 and 51 at D = -68 dBm

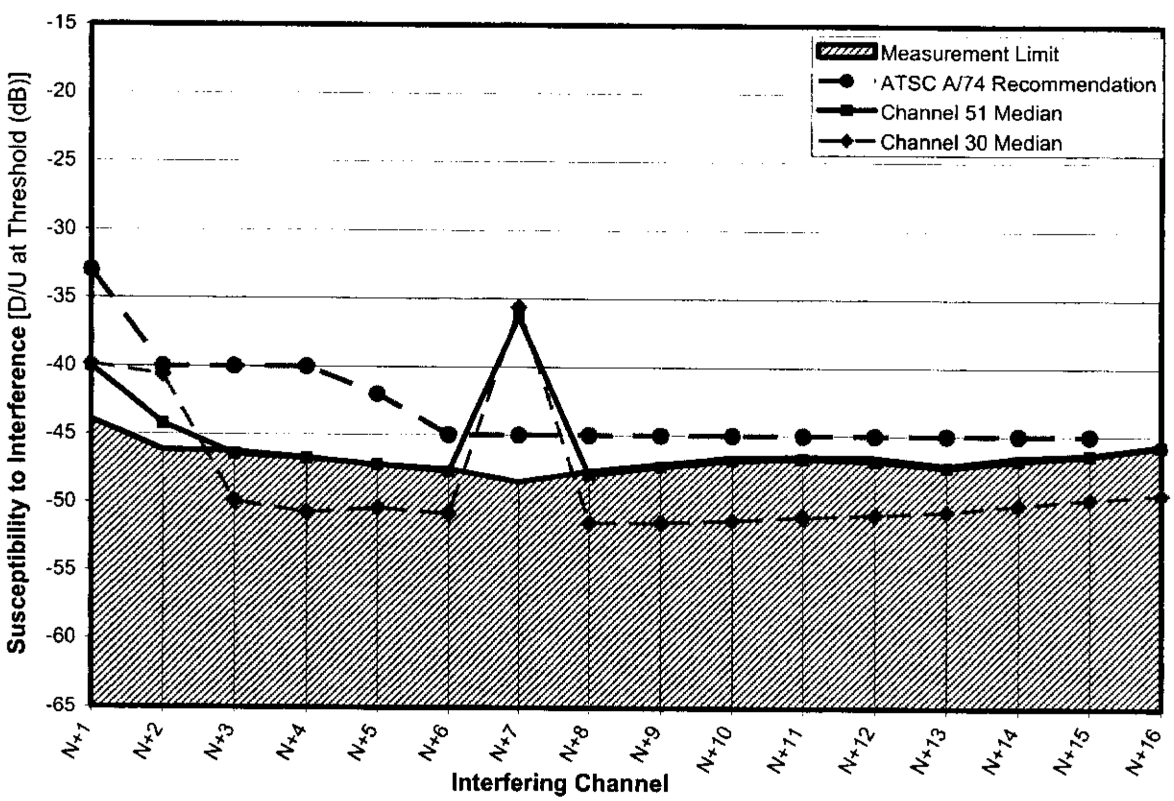

Figure 6-8. Comparison of Median D/U for 7 Receivers on Channels 30 and 51 at D = -53 dBm

CHAPTER 7
TESTS WITH DIFFERENT SIGNAL TYPES AND SOURCES

This chapter presents the results of tests performed to determine the influence of test signal sources and signal types on the interference rejection performance of DTV receivers. Specifically, the tests compare the following:

- Effect of two different 8-VSB signal generators as the *desired* signal;
- Effect of several types of *undesired* signals, including
  - ◊ White Gaussian noise bandlimited to the 3-dB width of an 8-VSB source;
  - ◊ 8-VSB;
  - ◊ DVB-H—an orthogonal frequency division multiplexing (OFDM) signal—set for a 5-MHz channel width; and
  - ◊ White Gaussian noise bandlimited to a 3-dB width of 1 MHz.

In addition, the tests include a repeat of the baseline test conditions (described below) to determine the amount of variation that may have been due to repeatability or equipment changes (spectrum analyzer). All of the tests discussed in this section were performed with the desired signal on channel 30 and set to a level of -68 dBm.

Spectra and bandwidths of the various sources can be found in Chapters 2 and 5. Figures 2-1 and 2-2 show spectra of the four undesired signals; bandwidths characteristics are shown in Table 2-1. Figures 5-7 and 5-8 show spectra of the two desired signal sources.

The baseline for comparison is:

- Desired signal source—Sencore ATSC997;
- Undesired signal type—white Gaussian noise (from an Agilent E4437B vector signal generator) bandlimited to match the 3-dB width of an 8-VSB signal.

The 1-MHz bandwidth tests were performed on one DTV receiver (N1) for channel offsets from N-16 to N+16. All other tests were performed on all eight DTV receivers, but were limited to the five non-adjacent channel offsets that exhibited the most interference potential among the receivers at low signal levels (Figure 5-16): N+2, N-2, N-3, N-4, and N-6. (Note that channels N-1 and N+1 were not tested because the Gaussian source did not have adequate band-edge rolloff to permit testing on first-adjacent channels.)

The baseline tests, a subset of the measurements presented in Chapter 5, were performed between August 30 and October 23, 2006. The comparative tests presented here, including the "repeat baseline" test, were performed between January 31 and February 6, 2007.*

The results for all tests except the 1-MHz bandwidth tests are summarized in Table 7-1. Individual results are presented in each section. Results for the 1 MHz tests are in the next section of this chapter.

Table 7-1 shows the means and standard deviations for the differences in D/U measurements between a "comparative test" configuration and the baseline configuration. The statistics are based on 35 measured values (7 receivers X 5 channel offsets), except in the case of the DVB-H signal, where 34 measurements were used for reasons explained in the DVB-H section below. The standard deviations shown are for the individual differences; standard deviation of the mean would be reduced from this by a factor of square-

* Dates are presented to address issues of whether observed differences were caused by possible changes in test setup performance or equipment. (A different spectrum analyzer was used for the comparative signal tests than for the baseline tests.) Though the baseline tests were performed about four months before the comparative tests, the "repeat baseline" test was performed as part of the comparative tests and was performed after the "SFU as D" test.

root of 34 or 35 (5.8 or 5.9) if the individual differences can be considered independent. Results are shown in hundredths of a dB to reduce round-off error, although D/U measurement resolution was 0.1 dB since the measurements were made by stepping the undesired signal in increments of 0.1 dB to locate the receiver's TOV.

Table 7-1. Comparative Signal Test Summary

Test Case	Test Dates	Signals		D/U Ratio Relative to Baseline (dB)	
		Desired Signal Source	Undesired Signal	Mean	Standard Deviation
Baseline	8/30/2006 – 10/23/2006	ATSC997	WGN	0	N/A
Repeat Baseline	2/02/2007 – 2/05/2007	ATSC997	WGN	-0.12	0.33
SFU as D	1/31/2007 – 2/1/2007	***SFU***	WGN	-1.14	0.40
8-VSB as U	2/06/2007 – 2/07/2007	ATSC997	***8-VSB***	-1.28	0.68
DVB-H OFDM as U	2/05/2007 – 2/06/2007	ATSC997	***DVB-H***	-0.40 (-0.25*)	1.09 (0.66*)

Notes:

- *WGN = White Gaussian noise bandlimited to 5.38 MHz 3-dB width.*
- *The means and standard deviations were across five channel offsets and seven receivers—a total of 35 measurements, except results marked "*" are for 34 measurements. Measurement results for receiver G4 were not included in these statistics for reasons discussed in the section of this chapter entitled, "Desired Signal Source: SFU Versus ATSC997"*

The "repeat baseline" test results differed from the baseline test results by an average of only 0.12 dB—a reassuringly small difference given the four-month delay and spectrum analyzer change between the baseline and "repeat baseline". Though the results in the table are presented relative to the original baseline tests, we can use the newer "repeat baseline" as the point of reference by subtracting -0.12 dB from the means. Doing so, we find the following.

- Use of the SFU as the *desired* signal source resulted in D/U ratios that were 1.0 dB lower (better) than were achieved with the ATSC997 (the source used for most of the tests presented in this report).* Thus the DTV receivers could tolerate about 1.0 dB more interference when the SFU was the desired signal source. This suggests that the ATSC997 may have had a slightly degraded performance that affected the results, at topic that was discussed in Chapter 5.
- An 8-VSB *interferer* results in D/U ratios that are 1.2 dB lower than those measured with a bandlimited white Gaussian noise interferer. Thus, the TV's are 1.2 dB less susceptible to out-of-band interference from an 8-VSB DTV signal than from a Gaussian-noise signal of comparable bandwidth.
- The OFDM DVB-H signal causes an interference effect comparable to that of bandlimited Gaussian noise based on the mean listed in parentheses in the table; this mean omits one measurement (in addition to those of receiver G4) for reasons discussed in the DVB-H section of this chapter.

* The ATSC997 was the desired signal source for all tests except as follows. The SFU was a desired source for: (1) some tests to identify effect of the desired signal source (here and in Chapter 5, "Effect of Desired Signal Source"), and (2) tests with $D = D_{MIN} + 3$ dB with non-adjacent interference. The Wavetech WS-2100 with an external Drake upconverter served as the desired signal source for tests with $D = D_{MIN} + 3$ dB with the undesired signal at N-1 or N+1.